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Maria Inês Oliveira Casqueiro

Dissertação de Mestrado

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Dissertação orientada pelo Professor Doutor Leonel Garcia-Marques e coorientada pela Professora Doutora Ana Sebastião

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To Zé, Rita & João

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Resumo

Diariamente tomamos decisões complexas que requerem tempo e esforço que não podemos despender. Compreender como decidimos em ambientes ambíguos com recursos cognitivos limitados torna-se essencial para todos nós. Este trabalho surge da intersecção da Psicologia e Neurociência, analisando a tomada de decisão cooperativa. O objectivo é analisar como diferentes níveis de glicemia influenciam a cooperação depois de um evento crítico. Aqui, a crise é operacionalizada como uma crise de recursos num dilema social. Esta investigação torna-se a primeira a explorar a relação entre glucose e cooperação pós-crise.

A nossa amostra consiste em 47 adultos voluntários de ambos os géneros, recrutados através do método de amostragem *snowball*. Usámos uma tarefa *commons dilemma* com duas condições de perigo de extinção de recurso (*High vs Low Danger*) e manipulámos os níveis de glicemia dos participantes administrando uma bebida rica em ou sem açúcar. Desta forma, a experiência consistiu num design factorial 2 Glucose (glucose vs placebo) x 2 *Danger* (*High* vs *Low*), inter-sujeitos.

Os dados sugerem que participantes com níveis mais elevados de glucose sanguínea são mais cooperativos num contexto pós-crise (e não antes) e principalmente quando há maior perigo de extinção de recursos (condição *High Danger*). Estes resultados implicam que a glucose sanguínea influencia processos de tomada de decisão, replicando estudos anteriores; e que pode influenciar as decisões cooperativas em alguns contextos. Assim, sugerimos que níveis de glicemia mais baixos estão associados a uma redução dos recursos cognitivos o que promove um processamento cognitivo intuitivo, estimulando o uso de certas heurísticas sociais.

Sugerimos que investigações futuras analisem quais as heurísticas sociais mais salientes em diferentes cenários pós-crise, sob diferentes níveis de glicemia. A combinação

de métodos da Psicologia, Neurociência e Computação, integrando assim diferentes áreas da Ciência Cognitiva, permitirá continuar a expandir o nosso conhecimento sobre a tomada de decisão cooperativa.

Palavras-chave: cooperação humana, dilema social, crise, glucose, recursos cognitivos, heurísticas

Abstract

Daily we face complex decisions that require time and effort that we do not possess. Understanding how we make decisions in uncertain environments with limited cognitive resources becomes essential to all of us. The present work arises from the intersection of Psychology and Neuroscience, focusing on cooperative decision-making. The goal is to examine how much we cooperate after a critical event, under different glycemic levels. Here, the crisis is operationalized as a crisis of resources in a social dilemma paradigm. This research becomes the first to explore the connection between glucose and post-crisis cooperation.

Our sample comprises 47 volunteer adults from both genders, recruited through snowball sampling. We used a commons dilemma task, with two post-crisis conditions of resource depletion (High vs Low Danger) and manipulated participants' blood glucose levels by administering either a sugar-rich or a no-sugar drink. Thus, the experiment consisted in a 2 Glucose (glucose vs. placebo) x 2 Danger (High vs. Low) factorial design, between subjects.

Results suggest participants with higher blood glucose levels are more cooperative only in a post-crisis context (and not before) and mainly under greater danger of resource depletion (High Danger condition). Our findings do not imply a direct causal link between brain glucose and cooperation but instead that blood glucose levels influence decision-making processes, replicating previous studies; adding it can influence cooperative decision-making in some contexts. We propose lower blood glucose levels are associated with lower cognitive resources that, in turn, promote an intuitive processing type, boosting the use of certain social heuristics.

We suggest that future research addresses which social heuristics are more salient in different post-crisis scenarios, under different glycemic levels. Combining methods from

Psychology, Neuroscience and Computation, thus integrating different areas of Cognitive Science, could expand our understanding of cooperative decision-making.

Keywords: human cooperation, social dilemma, crisis, glucose, cognitive resources, heuristics

Resumo alargado

Diariamente somos confrontados com decisões complexas que requerem tempo e esforço que não podemos despender. Compreender como tomamos decisões em ambientes ambíguos com recursos cognitivos limitados torna-se essencial para todos nós. O presente trabalho surge da intersecção de duas áreas da Ciência Cognitiva, Psicologia e Neurociência, analisando o processo cognitivo de tomada de decisão sob a forma de cooperação. A cooperação é essencial para a nossa sociedade, especialmente em momentos de crise. Por essa razão, o objectivo deste projecto consiste em examinar o quão cooperamos após um evento crítico, sob diferentes níveis de glicemia. Uma das principais premissas deste trabalho é a associação entre o nível de glicemia e recursos cognitivos, sendo que se espera que níveis inferiores de glucose no sangue estejam associados a uma redução de recursos cognitivos. Esta ideia é suportada pela diminuição de capacidades cognitivas em consequência de níveis mais baixos de glucose (e.g. Feldman & Barshi, 2007). O evento crítico é operacionalizado sob a forma de crise de recursos, através de um dilema social. Assim, esta investigação torna-se a primeira a explorar a relação entre glucose e cooperação pós-crise.

Definimos cooperação um comportamento que maximiza ganhos comuns (Vohs & Baumeister, 2007). Para estudar a cooperação humana temos de começar por compreender os mecanismsos que permitiram que esta emergisse. Rand & Nowak, (2013) propõem 5 mecanismos através dos quais a cooperação é seleccionada pela natureza, todos eles beneficiando o actor, quer directa ou indirectamente, quer a curto ou longo-prazo, favorecendo assim uma perspectiva de cooperação como fenómeno egoísta. Herbert Simon propôs um outro mecanismo em adição aos anteriores para explicar a emergência da cooperação: docilidade humana, explicada com base no altruísmo. Altruísmo é um comportamento que tem sempre um custo para o actor e beneficia um outro (West, Griffin, &

Gardner, 2007) e, assim, a cooperação altruísta envolve sempre um custo. Já a docilidade é definida como a tendência humana de aprender através dos outros, a nossa receptividade à influência social sem completa avaliação, o que pode aumentar a nossa *fitness* (Simon, 1990). Esta perspectiva já sugere uma base altruísta para a cooperação, pois os altruístas tendem a exibir este traço de docilidade. O altruísmo pode, assim, ser seleccionado pois a docilidade permite que os altruístas tenham maior *fitness* que os egoístas, na medida em que esta promove a aprendizagem social. Esta aprendizagem tem grandes vantagens para os indivíduos dóceis, nomeadamente a aquisição de conhecimentos, *skills* e comportamentos úteis no dia-a-dia. Este mecanismo da docilidade sugere, assim, que estamos predispostos a cooperar porque adquirimos este comportamento através da aprendizagem social, sem completa avaliação dos benefícios e prejuízos que esta nos pode trazer.

Aceitação sem completa avaliação é uma noção central para o mecanismo da docilidade. Mas porque tomamos decisões tão importantes, como cooperar ou não, sem uma avaliação cuidada? Isto ocorre porque a nossa racionalidade tem limites. Muitas vezes não temos tempo nem capacidade cognitiva para lidar com problemas complexos e, ao invés de recorrer a um raciocínio cuidado, usamos atalhos mentais chamados heurísticas. Estas heurísticas são regras gerais que nos permitem decidir com base em pouca informação, que por vezes nos induzem em erro mas frequentemente nos permitem chegar a uma boa solução (Tversky & Kahneman, 1974). O uso de heurísticas corresponde ao uso do sistema intuitivo, da perspectiva da teoria do processamento dual da cognição. De acordo com esta, temos dois sistemas de processamento: 1) intuitivo, que é rápido e automático; 2) deliberativo, que é lento, custoso e controlado (Kahneman, 2003). As heurísticas, especificamente heurísticas sociais, parecem promover a cooperação. De acordo com a *Social Heuristic Hypothesis (SHH)*, que se baseia no modelo dual da cognição, nós seres humanos cooperamos intuitivamente e apenas deliberando é que tomamos uma decisão no próprio interesse (Rand

et al., 2014). A cooperação intuitiva terá surgido da generalização de heurísticas sociais (respostas automáticas e vantajosas) que desenvolvemos nas nossas interacções sociais diárias.

Para analisar a cooperação, especificamente num contexto pós-crise, optámos por usar como paradigma um dilema de recursos – *commons dilemma*,. Neste tipo de dilemas, várias pessoas têm acesso a um conjunto de recursos (por exemplo, peixes num oceano, árvores numa floresta) e podem tirar tantos itens quanto quiserem até um dado limite. Tal como no mundo real, este recurso regenera-se periodicamente, permitindo que se vá retirando itens de forma sustentável. Contudo, se tirarmos demasiado (*overharvesting*), o recurso extingue-se e enfrentamos uma crise de recursos. Assim, surge o dilema: todos querem ter o máximo de itens possível mas para evitar que o recurso se extinga e poder continuar a retirar, temos de nos restringir. Há diversas variáveis individuais e situacionais que influenciam a cooperação neste tipo de dilemas, contudo, não existem estudos sobre quão cooperamos depois de uma crise, pelo que apenas podemos tentar antecipar com base na literatura existente.

Já expostas as bases teóricas acerca da cooperação humana e apresentado o paradigma escolhido para a estudar, resta compreender de que forma é que a glucose pode influenciar a cooperação. Actualmente não há estudos sobre a relação entre a glucose e a cooperação, apenas sobre o efeito da glucose na tomada de decisão. A glucose é o principal substrato energético do cérebro e, dado que este não a consegue sintetizar, a glucose tem de ser transportada pela corrente sanguínea para suportar a actividade neuronal cerebral. Consequentemente, quando estamos num estado hipoglicémico (quantidade de açúcar no sangue inferior ao normal) o nosso cérebro opera de forma diferente. Parece que menores níveis de glucose no sangue estão associados a uma redução das capacidades cognitivas superiores tais como atenção, memória de trabalho e controlo executivo (Feldman & Barshi, 2007). Ademais, até alterações relativamente subtis nos níveis de glucose podem ter um

impacto mensurável no pensamento e comportamento (Gailliot & Baumeister, 2007) e ainda antes de atingir um estado hipoglicémico já se verifica uma redução de algumas capacidades cognitivas (McElroy, Dickinson, & Stroh, 2014). No que respeita os efeitos da glucose na tomada de decisão, uma meta-análise recente revelou que menores níveis de glucose estão associados a uma maior *risk seeking*, maior *future discounting* e a um estilo de processamento mais intuitivo (Orquin & Kurzban, 2016). Com base nesta evidência prevemos que indivíduos com maiores níveis de glucose sejam mais cooperativos na nossa tarefa experimental.

A nossa amostra consiste em 47 adultos voluntários de ambos os géneros, recrutados através do método de amostragem *snowball*. Usámos o programa FISH 5.0, um *commons dilemma* em que peixes num oceano representam o recurso. A tarefa consiste em 3 etapas. Na 1ª etapa o recurso decai lentamente, podendo chegar à 10ª ronda. Numa 2ª etapa surge uma crise, o recurso extingue-se muito cedo (3ª ronda). Numa 3ª etapa, temos 2 condições pós-crise, inter-sujeitos: uma em que o recurso decai lentamente (*Low danger*, semelhante à 1ª etapa); uma em que o recurso decai mais rapidamente (*High Danger*). Além das duas condições pós-crise (*High vs Low Danger)*, manipulámos também os níveis de glucose sanguínea dos participantes administrando uma bebida rica em açúcar ou sem açúcar. Desta forma, a experiência consistiu num design factorial 2 Glucose (glucose vs placebo) x 2 *Danger* (*High* vs *Low*), inter-sujeitos.

Os dados sugerem que os participantes com níveis mais eleveados de glucose sanguínea são mais cooperativos num contexto pós-crise (e não antes) e principalmente quando há maior perigo de extinção de recursos (condição *High Danger*). Estes resultados não implicam uma ligação directa e causal entre os níveis de glucose no cérebro e cooperação mas sim que a glucose sanguínea influencia processos de tomada de decisão, replicando estudos anteriores; e que pode influenciar as decisões cooperativas em alguns contextos.

Assim, sugerimos que níveis de glicemia mais baixos estão associados a uma redução dos recursos cognitivos o que, por sua vez, promove um processamento cognitivo intuitivo, estimulando o uso de certas heurísticas sociais. Especulamos que o grupo placebo do nosso estudo tenha seguido a heurística de *imitate the successful*: que procuremos pela pessoa mais bem sucedida e imitemos o seu comportamento (Gigerenzer, 2008). Como o objectivo da tarefa era ter o máximo de pontos no final, pensamos que os participantes consideraram que o jogador mais bem sucedido era o que tinha mais pontos (mais ganancioso) e guiaram o seu comportamento pelo dele.

Terminamos este trabalho sugerindo que investigações futuras analisem quais as heurísticas sociais mais salientes em diferentes cenários pós-crise, sob diferentes níveis de glicemia. Através da combinação de métodos da Psicologia, Neurociência e Computação e assim integrando diferentes áreas da Ciência Cognitiva, poderemos continuar a expandir o nosso conhecimento sobre a tomada de decisão cooperativa.

Palavras-chave: cooperação humana, dilema social, crise, glucose, recursos cognitivos, heurísticas

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Introduction

Nowadays we are constantly faced with complex decisions, which require time and effort that we do not possess. Most of our decisions take place in the social realm and among these we are specifically interested in cooperative decision-making. Cooperation is a pillar of our society, either in a large scale such as cooperation between nations or multinational companies; or in a smaller scale, with family members, friends and even strangers. There are several individual and situational variables that influence human cooperative behavior and we are specifically interested in cooperation after a critical situation. A crisis is an event that results in unstable and dangerous situation, affecting an individual, group, community or even the whole society.

We face several crisis in the current days such as the economic, politic and social crisis, several natural catastrophes, among others. Let us take the example of natural catastrophes. The closer we are or feel towards the victims of these catastrophes, the more likely we are to aid them. The Americans who volunteered to help during the California floods (Yurieff, 2017), the 12,5 million donated by the Portuguese to the victims of the Pedrogão wildfire ("Donativos de Pedrógão," 2017) and the 14 billion US dollars donated to the victims of the 2004 Indian Ocean earthquake and tsunami (Falk, 2013). These are just a few examples of large-scale cooperation after a crisis. However, some catastrophes received less media coverage and elicited less help such as the recent floods in India. Therefore, even when the crisis is evident, our response is not always to cooperate. Cooperation often comes with cost.

Another crisis we face, and perhaps a more silent one, is resource crisis. If we consume a natural renewable resource at a higher rate than the Earth is able to replenish it, the resource will be in danger of depletion. A report from 2008 (almost a decade ago) revealed we humans are using 30% more resources than the Earth can replenish each year, leading to deforestation, degraded soils, polluted air and water, and dramatic declines in numbers of fish and other

species (Jowit, 2008). To study human cooperation after a crisis in the laboratory, we will use a resource crisis simulation.

What factors influence human decision-making in terms of cooperation after a crisis? Common sense says that the particularities of the situation and our cultural background and values will probably have a strong impact. In other words, cooperating or not will depend on the situation and the individual. Another less evident variable is our current mental state. Our mental or cognitive state, such as being distracted, confused or curious, clearly influences how we process information and how we make decisions. Imagine a friend calls you asking you to help him move in. Whether you are feeling mentally exhausted or rested will probably influence your decision to help or not. Therefore, it is natural that our current cognitive state affects how we make decisions, namely, our decision to cooperate with others.

One factor that greatly influences our cognitive state and ability is our blood glucose levels (Orquin & Kurzban, 2016). This is not surprising since the brain cannot synthetize glucose, its main energy source (Mergenthaler, Lindauer, Dienel, & Meisel, 2013), requiring virtually a continuous supply of glucose from the circulation (Cryer, 2007). Just think of occasions when there have been several hours since your last meal and you feel like you are not thinking straight. Even in healthy individuals, blood glucose levels vary plenty throughout the day, although they rarely experience episodes of hypoglycemia (Desimone & Weinstock, 2000; Rooijackers, Wiegers, Tack, van der Graaf, & de Galan, 2016). Considering our brain function relies on glucose as fuel and we experience large glycemic variability, we recognize our brain function and decision-making abilities may vary with our glucose levels. Having this evidence in mind, we arrive to the research question behind this project: How different blood glucose levels influence human cooperation after a crisis?

The relevance of answering this question goes beyond fundamental research. Since cooperative behavior is a basic element of society and its individuals, understanding what

influences our decision to cooperate or not; or to what degree we cooperate is essential to promote this behavior. Moreover, the post-crisis context is of particular relevance, since a crisis implies something went wrong in the past and we need to work together and adapt, implementing a different strategy for the future. Although there is no denying that one's social values are of major importance, our blood glucose levels could potentially be very pertinent in determining cooperative behavior, even more so after a crisis. During the day, our glucose levels fluctuate and we are not always at the top of our reasoning abilities when we face new and complex problems. Many of these situations require deliberation and cooperation to reach a good solution. Thus, studying cooperative behavior under different glucose levels in critical situations is relevant for all individuals. This is particularly significant for those with stressful jobs such as police officers, firefighters, airline pilots and military personnel.

This project arises from an intersection between two areas of Cognitive Science, Psychology and Neuroscience, with decision making as the cognitive process of interest. Decision-making is framed as *how much should I cooperate*, to be studied through a social dilemma. The contribution from Neuroscience stems from the field of neuroenergetics, which has mainly focused on the role of glucose in neural function. The contribution of Psychology comes from the study of cooperative behavior in a group context, a topic of interest in social psychology.

The literature review supporting this thesis comprises three chapters. We begin by analyzing how human cooperation emerged, its underlying mechanisms and the theoretical framework offered by the Social Heuristic Hypothesis. The second chapter centers on the paradigm we will use to study human cooperation– *the commons dilemma* – a social dilemma. Here we focus on the individual and situational variables that influence our behavior in such contexts and try to anticipate how much we cooperate after a crisis. After describing the theoretical framework on human cooperation and presenting the paradigm used to study it, we

move on to understand how glucose can influence cooperation in humans. Therefore, the third and final chapter begins by describing how glucose is metabolized by the brain, how it influences decision-making and how it may influence cooperative behavior. We close this review by raising our hypothesis, followed by the method and results sections. Finally, we discuss our data, present the study's limitations and give some directions for future research.

I. Theoretical background

1. Emergence of human cooperation

What is cooperation?

Answering this question has been proven difficult. In evolutionary theory, cooperation is a behavior that benefits the recipient and may or may not be costly to the actor (West et al., 2007), with benefits referring to increases in reproductive success – *fitness* – of the recipient. Fitness is not defined by how much an organism lives but instead by the expected number of offspring of an organism or, in other words, by the probability of successful reproduction (Mills & Beatty, 1979). From the perspective of the social sciences, cooperation belongs to a class of prosocial behaviors, that is, voluntary actions that are intended to help or benefit another individual or group of individuals (Eisenberg & Mussen, 1989), such as helping, sharing, volunteering and cooperating (Tomasello, 2009). Cooperation is defined by social psychology as the tendency to maximize outcomes for self and others, as "doing well together" (Vohs & Baumeister, 2007). A more precise definition of cooperation is as behaviors that are beneficial to the recipient, but can be either beneficial or costly to the actor (West et al., 2007)

It is possible to observe cooperation in different species, being a widespread phenomenon both within and between species (Melis & Semmann, 2010). In humans, we can find several examples of cooperation in our daily life. When we are at work, we cooperate with our colleagues to produce a desirable outcome – e.g. deliver the project within the deadline. Cooperation occurs at a larger scale when, for example, countries cooperate by forming alliances to promote counter-terrorism, by sharing intelligence, developing joint military tactics and law enforcement, etc.

However, we also observe several examples of competition. As with cooperation, we can see competition from two angles. From the perspective of social sciences we define

competition as the tendency to maximize relative advantage over others, as "doing better than others" (Vohs & Baumeister, 2007). From the lenses of evolutionary theory we define it as behaviors that benefit the self but harm others. as interactions where the presence of one individual lowers the reproductive success – fitness – of another (West et al., 2007).

There is a long history of us humans competing for resources such as food, water and territory. These days, those resources are accessible in most developed countries and we compete for other valuables like jobs, housing, social status, etc. There is also competition in a larger scale, between countries for economic growth and national security.

Now we arrive at an intriguing question: in situations where each individual has an incentive to be selfish and compete, how did cooperation ever develop? This problem was posed some decades ago by Axelrod in 1984 and was portrayed as the cooperation paradox: *under what conditions will cooperation emerge in a world of egoists without any central authority*? In other words, how can we sustain cooperation without any authority to enforce it, when there is great benefit in competing? To answer this seemingly paradoxical phenomenon we need to analyze how cooperation emerged.

Emergence of cooperation

We will present some evidence on the mechanisms underlying cooperative behavior that may tempt the reader to accept the idea that cooperation is ultimately a selfish phenomenon. Later, we demonstrate that cooperation can be a reflection of pure altruism and that this trait was selected by nature.

a. Cooperation as egoism

Natural selection actually opposes the evolution of cooperation unless specific mechanisms operate: direct reciprocity, indirect reciprocity, spatial selection, multilevel selection, and kin selection (Rand & Nowak, 2013).

The mechanism of **direct reciprocity** arises if the same two individuals have repeated interactions. This mechanism is based on the idea that subject A may pay the cost of cooperating with subject B today to earn reciprocal cooperation of B in the future. **Indirect reciprocity** on the other hand, emerges if there are repeated encounters within a population and third parties observe or can find out about them. The information that subject C is cooperative may spread across the population through communication, building a good reputation for C that will increase the likelihood of reciprocation in the future. A good reputation also enhances the likelihood of access to sexual partners and resources (Van Lange, Balliet, Parks, & Van Vugt, 2014a).

Another mechanism is **spatial selection**. Since individuals interact with those around them, clusters of cooperators can emerge, even if surrounded by defectors/competitors (Rand & Nowak, 2013). This clustering increases the likelihood of cooperators interacting with other cooperators, making them earn higher payoffs/rewards than defectors. When there is intragroup and intergroup competition, defectors may win within groups but groups of cooperators may outperform groups of defectors. This process of **multilevel selection** results in the selection of cooperators. Finally, cooperation also emerged through **kin selection**, which relates to the concept of *inclusive fitness*. Our organisms seek to maximize inclusive fitness, which is the combination of increasing the reproduction of our current body - direct fitness – or increasing the reproduction of other bodies that carry a copy of ourselves – indirect fitness (Van Lange et al., 2014a). We can see this in terms of a gene trying to propagate copies of himself

Taken together, the previous mechanisms provide good reasons for the natural selection of cooperation and, therefore, why we observe this apparently paradoxical behavior across species. These mechanisms all share the premise that individuals always benefit from cooperation, directly or indirectly, in a short or long-term. Hence, they are all forms of selfish or strategic cooperation, since the cooperators' goal is his/her own benefit.

From the above examples, we might be tempted to accept human nature is necessarily selfish. That we only cooperate because we expect some return and that cooperation is a strategic and a self-interest act. However, how could we explain cooperative behavior when there is no benefit to the self, at no point in time? For example, how can this view account for people who risk their lives to help a stranger? In a recent TED Talk, Abigal Marsh answered this question by saying there are genuinely altruistic behaviors and presented compelling neurobiological evidence supporting this idea (Marsh, 2016). For the time being let us consider altruism as voluntary, costly behavior motivated by the desire to help another individual.

It seems that the brains of altruistic people are fundamentally different in three characteristics: facial emotion recognition, amygdala activity and size. Altruists are *better at recognizing fearful expressions*, which are social cues that elicit compassion and desire to help. This recognition is mediated by the amygdala complex, which is a part of the neural circuitry critical for emotion, having a role in emotional reactivity and learning, among other functions (Gallagher & Chiba, 1996). Not surprisingly, altruists also display *higher amygdalar reactivity* to fearful stimuli and a *larger amygdala* than average (by approximately 8%). Conversely, the brain of psychopaths, who lack compassion and desire to help others, operates in the other side of the spectrum. Unlike altruists, psychopaths have poorer recognition of fearful expressions, their amygdala is under reactive to fear stimuli and is smaller than average (by 18-20%).

Now that we have presented evidence that cooperation is not always selfishly motivated and that real altruism exists, we have still not explained the mechanism that underlies the selection of cooperation through altruism. Adding to the previous five mechanisms for the selection of cooperation, Herbert Simon proposed another mechanism that adds to the previous ones – docility. For Simon, cooperation can also be an altruistic behavior, not necessarily a selfish one.

b. Cooperation as altruism

Altruism is a behavior that is always costly to the actor and beneficial to the recipient (West et al., 2007). For the purposes of understanding cooperation, we are interested in the definition of altruism that stems from genetics. Let us consider altruism the behavior that increases, on average, the reproductive fitness of others at the expense of the fitness of the altruist (Simon, 1990). Therefore, we conclude selfish individuals have higher fitness than altruists will. If altruism, by definition, reduces the fitness of the individual, how can this behavior be selected? Simon argues that even though it reduces the fitness of the altruist, it can increase the average fitness of society.

This theory accounts for altruism on the basis of **docility**: the human tendency to learn from others, our receptivity to social influence. Herbert's main argument is that docility can actually increase our fitness. As we shall explore further, there are many times where we do not make rational decisions because there is neither time nor processing power to do so. Given this limited rationality, docility encourages individuals to adopt culture-transmitted behaviors, such as cooperation, without evaluating how much these behaviors contribute to their personal fitness. Acceptance without full evaluation is at the core of this docility mechanism, Simon says. One example of this docility mechanism is many of us are willing to accept less cholesterol would be beneficial to our health, without reviewing clinical studies on the matter.

Previously it was mentioned that selfish individuals have higher fitness than altruists simply because altruism comes with a cost to the self. Nevertheless, docility allows altruists to have higher fitness than selfish individuals. Docile individuals are prone to social learning, and this has two main contributions to their fitness: 1) provides *knowledge and skills* that are useful in daily life; 2) and passes "proper behaviors" such as goals, values and attitudes, which lead to supportive responses from others. Social learning prevents docile individuals from "reinventing the wheel", rendering their learning more efficient and making a massive contribution to their fitness. As long as the cost of altruism that society imposes on docile individuals is smaller than the knowledge and skills acquired from docility, altruists will have higher fitness than selfish individuals will. In sum, this leads to the conclusion that we are predisposed to cooperate because we acquire this behavior from social learning without giving it much thought.

Before going any further, we need to understand something that is at the core of the docility mechanism, which is acceptance without full evaluation. Why would we make important decisions – such as whether to cooperate or not – without careful reasoning? If we did, it would cost us too much time and effort. In addition, there is a faster and sometimes more efficient alternative.

Bounded rationality

Social environments often involve complexity and uncertainty and we are frequently constrained by lack of information and limited cognitive resources, since our brain has finite processing power. Even we had quantum computing processing abilities, there is no way we could possibly make "the optimal decision" for all decisions in our day to day.

The classic idea that we are strictly rational beings striving for optimization has long been abandoned. Nowadays, it is widely accepted that we not always decide by *reasoning*, resorting instead to *intuition*. Here intuition is a process that allows problem solving without awareness or with incomplete awareness of the process that lead to the solution (Polič, 2009). We can relate to this feeling by recalling situations where the solution comes to us without much thought or deliberation. This processing mode can be beneficial since it is effortless and time-saving but can also lead us to make mistakes.

The distinction between these two types of cognitive processes - intuition and reasoning - was labeled as System 1 and System 2 (Stanovich & West, 2000). Later, Kahneman, (2003) proposed a dual system view of cognition that differentiated these two styles of processing. System 1 (intuition system) is fast, automatic, effortless, associative and difficult to control. System 2 (reasoning system) is much slower, serial, effortful, rule-governed and deliberately controlled.

The intuition system is associated with heuristics, a type of processing or a mental shortcut that greatly simplifies decision tasks (Tversky & Kahneman, 1974). Our rationality is bounded by heuristics and cognitive biases as well: heuristics are deviations from prescribed procedures while cognitive biases are deviations from correct responses (Polič, 2009). Below we present an example for each.

One of the most frequent cognitive biases is the **confirmation bias**, which is our predisposition to search, interpret and select information that confirms our beliefs, expectations and hypothesis (Nickerson, 1998). Simultaneously, we tend to underestimate or even disregard information that disproves them. For instance, a reporter who is writing an article with a major story may only interview experts that support his/her views on the issue.

One common heuristic is the **anchoring and adjustment heuristic**. Every so often, we estimate values (such as price, years, weight) from a base value and then adjust our final answer

(Tversky & Kahneman, 1974). We anchor our answer in that base value, even if unrelated, and then adjust it, usually insufficiently. Let us take the example provided by Critcher & Gilovich, (2008). In their study, participants saw a photo of a linebacker with a description of his past performance. Half of the participants saw a photo with the number "54" on the jersey and the other half saw the same photo but with the number "94", as seen in Figure 1.1.

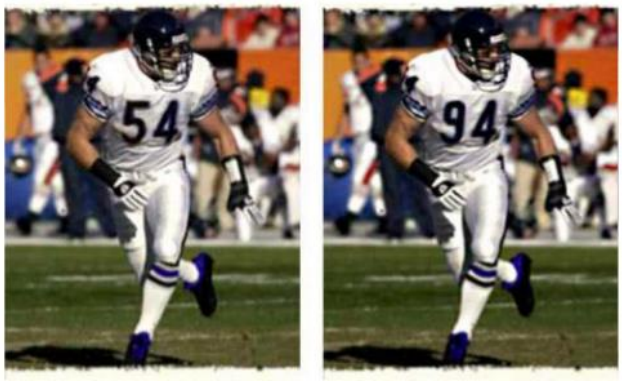

Figure 1.1 The two linebacker photos presented between subjects. Adapted from "Incidental environmental anchors," by C. R. Critcher and T. Gilovich, 2008, *Journal of Behavioral Decision Making, 21*, p. 244. Copyright 2007 by John Wiley & Sons, Ltd.

Participants were later asked to estimate the linebackers' performance in the coming playoffs. Those who saw him wearing the jersey 94 estimated that his performance would be better than did those who saw him wearing jersey 54. Thus, participants anchored on the number displayed on the jersey – a completely irrelevant aspect– and failed to adjust the value when estimating athletic performance.

Why do we use heuristics after all? If this type of intuitive processing leads to severe and systematic errors, why do we keep using it? Heuristics not only allow us to simplify complex cognitive tasks but also are also quite useful and have surprisingly good results (Tversky & Kahneman, 1974). So, the classical explanation is we use an accuracy-effort trade-off: since the search and processing of information cost time and effort, heuristics tradeoff some loss in accuracy for faster and more economical cognition (Gigerenzer & Gaissmaier,

2011). However, this is not always true and heuristics are sometimes less costly and more efficient than sophisticated statistical methods. The current explanation is we have an ecological rationality, that the environment of the decision is crucial in selecting which strategy is better and not necessarily "the best one". Here is where the concept of satisficing becomes relevant: the idea is we need not choose the optimal solution, only one that is good-enough, one that satisfices (Gigerenzer & Brighton, 2009).

In short, our limited rationality stimulated the development of faster and effortless strategies – heuristics. Occasionally, these heuristics lead us to mistakes (e.g. anchoring and adjustment heuristic) but often allow for a "good-enough solution", performing better than approaches that are more rational. In the following section, we explore how heuristics, specifically social heuristics, are associated to cooperative behavior.

Social Heuristics Hypothesis: intuition favors cooperation

Generally, social heuristics are our intuitive responses in complex and uncertain social environments. We often do not have the time or cognitive resources to make a careful and deliberate decision and resort instead to these mental shortcuts. So how do these social heuristics shape our cooperative behavior? The reflective model of prosociality suggests our intuitive response is to be selfish and cooperation requires deliberate thinking. Alternatively, the intuitive model defends we are predisposed to cooperate (strengthening Simon's idea on docility), and reflection leads to self-interested choices.

Empirical evidence supports the intuitive model through three major arguments in favor of intuitive prosociality (Zaki & Mitchell, 2013). First, there are *behavioral signs of automaticity* of intuitive behavior: we make prosocial decisions faster than selfish ones; reducing ability to exert self-control increases cooperative behavior; and inducing intuitive

processing increases cooperation. Second, studies on the *neural bases of automaticity* indicate prosocial choices' fail to recruit brain regions associated with reflective control but instead engage regions associated with reward, suggesting prosociality may reflect a form of reward seeking. Third, prosocial behaviors emerge in *early development*. Young children often exhibit prosocial behaviors that are both costly and non-rewarded. For example, toddlers with 18 months of age already display prosocial behaviors, while controlled behaviors seem to come later, between 22 and 48 months of age (Garon, Bryson, & Smith, 2008).

A theoretical model that seems to explain all the empirical evidence gathered so far is the Social Heuristic Hypothesis (SHH). This theory considers cooperative decision-making within the dual-process framework, proposing a connection between intuition and cooperation. This reinforces Simon's idea of human docility that we are predisposed to cooperate. According to the SHH, intuitive cooperation arises from the overgeneralization of social heuristics, the automatic and advantageous responses we develop in our daily social interactions (Rand et al., 2014). When confronted with atypical situations, more reflective and deliberative processes may override these automatic responses, resulting in a more advantageous behavior in that context. In other words, intuition is based on these social heuristics which we generalize our default response while deliberation, conversely, allows us to adjust to the specific social situation we are facing.

Several studies looked into the effect of processing type – intuitive vs deliberative – on human cooperative behavior in economic games[1]. This line of research uses different methods to promote an intuitive processing style, namely by increasing cognitive load, depleting cognitive resources, creating time pressure or inducing intuitive decision-making. These studies present strong evidence that intuition favors cooperation, as predicted by the SHH (e.g.

[1] Economic games are games where subjects make decisions about how to allocate real money/points between themselves and others (Rand, 2016). These games are a useful instrument to study human cooperation in the lab, as we shall see in the next chapter.

Døssing, Piovesan, & Wengström, 2017; Rand et al., 2014; Rand, Greene, & Nowak, 2012; Rand & Nowak, 2013; Roch, Lane, Samuelson, Allison, & Dent, 2000)

This notion is also supported by studies using a computational approach. It seems that depending on the probability of reciprocal consequences (future interaction), evolution favors individuals/agents who: 1) always intuitively defect; or 2) who are intuitively predisposed to cooperate but when deliberating switch to defection if it is in their self-interest (Bear & Rand, 2016). This second class of agents, who are successful in diverse environments, provides further support for the ideas of human docility and the SHH.

Rand et al., (2014) tested the SHH inducing intuition or reflection by creating time constraints while subjects played economic cooperation games. Time pressure induces subjects to rely on intuition and time delay on reflection. These authors examined 15 studies and their results confirm the predictions of SHH: that on average time pressure increases cooperation comparing to time delay; and that cooperation remains constant under time delay, with reflection leading to selfishness.

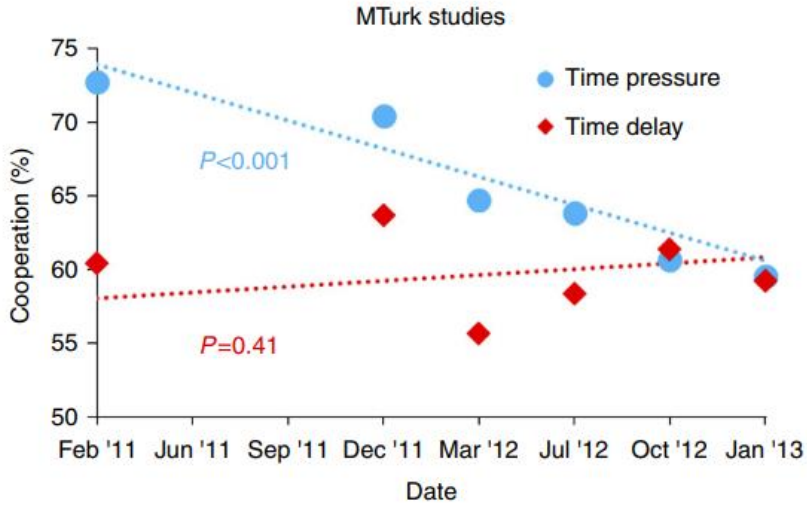

Figure 1.2 The effect of time pressure on cooperation in a one shot economic game. Adapted from "Social Heuristics Shape Intuitive Cooperation," by D. G. Rand, A. Peysakhovich, G. T. Kraft-Todd, G. E. Newman, O. Wurzbacher, M. A Nowak and J. D. Greene, 2014, *Nature Communications, 5,* p. 6. Copyright by Macmillan Publishers Limited.

Authors also observed previous experience with these games moderates the time pressure effect. As we can see in Figure 1.2, as subjects (in blue) became more experienced with these economic games, less cooperative they became, managing to deliberate even under time pressure. Their previous experience probably undermined their cooperative intuitions, allowing them to remodel their automatic responses.

The previous pattern of results emerges in one round (one-shot) economic games, where the optimal answer is to always defect, although we many times cooperate in this setting. What happens when we play several rounds with the same people? In these repeated games, the optimal choice is more difficult to define. Døssing, Piovesan, & Wengström, (2017) used a cognitive load manipulation to block deliberative thinking and let subjects play a repeated economic game in 4-person groups. Authors observed that higher cognitive load increased the cooperation levels in the first rounds but this effect weakened in the following rounds, becoming more difficult to interpret. Rand & Nowak, (2013) had two subjects play a repeated economic game and looked into subjects' decision times. They observed that if the partner cooperated in the previous round, faster decisions were significantly more cooperative but if the partner did not cooperate in the previous round, faster decisions were significantly less cooperative. Authors concluded that, in repeated settings, it is intuitive to reciprocate. That is, cooperate if others have cooperate and defect if others defected, a strategy termed *tit for tat* (Imhof, Fudenberg, & Nowak, 2007).

A recent meta-analysis investigated the role of intuition and deliberation on cooperation using 67 studies (Rand, 2016). These studies manipulated cognitive processing to be more intuitive vs deliberative and looked into cooperative behavior in economic games. The SHH was theoretical framework guiding this analysis, making predictions on the effect of cognitive processing on two forms of cooperation: pure and strategic cooperation. Pure cooperation occurs when there is no self-interested motive to cooperate (in one-shot games) whereas in

strategic cooperation there are self-interest motives to do so (in repeated games). SHH predicts promoting intuition over deliberation should have: no effect on strategic cooperation, since both intuition and deliberation favor cooperation; a positive effect on pure cooperation, since deliberation favors noncooperation, with some degree of variability based on individual past experiences. As predicted by the SHH, promoting intuition over deliberation increased pure cooperation by 17.3% but had no overall effect on strategic cooperation.

In sum, we have reasoned that human docility allowed the natural selection of altruists and that true altruism exists. A key concept for docility is accepting information without full evaluation, which occurs because of our bounded rationality. Given our limited cognition, to make sense of a complex and uncertain world we resort to mental shortcuts – heuristics that allow for fast decisions without considerable knowledge. In complex social contexts, we use social heuristics, which shape our cooperative behavior. According to social heuristics hypothesis, supported by vast empirical evidence, we cooperate intuitively (default response), using deliberation in more atypical scenarios to adapt to specific situations.

Now that we understand how human cooperation emerged and which cognitive processes underlie it, we can turn our attention towards what shifts our decision from cooperation to defection.

Factors influencing human cooperation

What variables are at play when we decide to cooperate? We can divide the answer in two broad categories: dispositional and situational factors. Dispositional variables concern personality traits, which are relatively stable individual characteristics, such as one's social values or culture. Situational variables on the other hand, are inconstant and we can further classify them into external or internal. External variables relate to the particularities of the

environment, such as where the decision takes place, how many people are involved, what are the “ground rules”. Internal variables are associated with the individual’s internal state, such as current mood and cognitive resources. Here we are interested in glucose levels as an indicator of cognitive resources. Since glucose is the main fuel in the brain, our premise is that deprivation from the main energetic substrate will reduce our cognitive resources, as we shall explore later on.

The next chapter focuses on social dilemmas, a powerful tool to study human cooperation. There are several social dilemma types but to answer our research question we chose to focus on resource dilemmas, also known as commons dilemmas.

2. Cooperation in a commons: what happens after the tragedy?

Before answering this question, we need to understand what constitutes a social dilemma and the characteristics of a commons dilemma. Next, we will attempt to operationalize cooperation in such dilemmas and describe the variables influencing cooperation in a commons. Only after reviewing such evidence and understanding how we behave in commons dilemmas, can we reflect about how we behave *after* a tragedy of the commons (crisis). However, not many studies focus on this topic.

What is a social dilemma?

Roughly, a social dilemma is a situation where there is conflict between an individual's short-term interest and the long-term interest of the collective (e.g. Van Lange, Joireman, Parks, & Van Dijk, 2013). Actions are expressed in terms of "cooperation" and "defection" and each individual always receives a higher payoff for defecting than for cooperating, but all are better off by cooperating than if all defect (Dawes & Messick, 2000). In other words, individual rationality leads to collective irrationality.

Some real world phenomena occur precisely because of this conflict between individual and collective interests, such as resource depletion, low voter turnout and overpopulation. Let us take the example of overfishing to illustrate the social dilemma behind resource depletion. Each fishing company wishes to fish as much as possible to increase its profits. However, if all fish excessively, fishes will be in danger of extinction. It is sensible to establish a limit for each company to fish, in order to preserve this resource. Interestingly, if all choose to cooperate and respect this limit, the bigger the temptation to fish above the limit. Again, if everyone does this, we are in danger of resource depletion.

Social dilemmas in the lab

Social dilemmas were the focus of different fields such as economics, biology, psychology, sociology and political science. The most influential theoretical approach was game theory, which is a mathematical formalization of social interaction and strategic behavior (Rand & Nowak, 2013) . Game theory lies on the premise that individuals are rational agents who are motivated to maximize their gains and minimize their losses. Therefore, it predicts individuals will defect in one-shot interactions since this choice maximizes profit and minimizes cost. Yet, experimental studies show people deviate from rationality, cooperating even in anonymous one-shot situations (Dawes & Thaler, 1988; Rand, 2016; Rand et al., 2014; Rand & Nowak, 2013), demonstrating we are not always trying to maximize gains.

The social dilemma that received more attention in the game theory literature was the Prisoner's Dilemma. It describes a game involving two players, each of whom chooses between cooperation or defection, where it is individually optimal to defect (regardless of the partner's choice) but socially optimal to cooperate (Rand & Nowak, 2013) (see Appendix A for a detailed description).

However, the prisoner's dilemma games were criticized by their lack of ecological validity, since very few social situations have only one interaction partner and only two possible actions (cooperate vs defect) with defined outcomes for the self and the other (payoff) (Van Lange, Balliet, Parks, & Van Vugt, 2014b). Since our daily decisions of cooperation rarely come in binary choice types of cooperating vs competing but, instead, in *how much* we cooperate or compete, researchers developed more complex research paradigms, such as public goods dilemmas and resource dilemmas (also known as give-some and take-some dilemmas).

These belong to the class of N-person dilemmas, which deserve further attention. N-person games have two characteristics. Let D(m) be the payoff to the defectors in an N-person game where m players cooperate, and let C(m) be the payoff to the cooperators when m players

(including themselves) cooperate (with m ranging from 0 to N-1). A social dilemma game is characterized by two simple inequalities (Dawes, 1980):

1. $D(m) > C(m + 1)$. An additional cooperator makes less than had he/she remained a defector.
2. $D(O) < C(N)$. Universal cooperation among the N players leads to a greater payoff to each player than does universal defection.

In a **public goods dilemma**, each individual owns some resource and can ***give some*** of it to provide an entity or service that all group members may use (Van Lange et al., 2014b). Here the resource is usually government provided, such as street lighting, environmental protection (air quality, street cleaning), national defense systems, among others. Public goods are both non-excludable and non-rivalrous, that is, everybody has access and one individual's consumption does not reduce the amount available to others. In the case of public goods, we face the problem of free-riding. Free-riders are those who benefit from resources, goods, or services without contributing by paying the costs that sustain them (Johnson, n.d.)

In a **resource dilemma** people have access to a pool of limited size and each individual can ***take some*** of it from the resource up to a limit (Van Lange et al., 2014b). The resource is a common good, such as fisheries, forests, etc. Common goods are non-excludable but rivalrous to a certain degree because everybody has access and one individual's consumption can potentially reduce the amount available to others. If everybody takes less than the total pool size, each person receives the payoff it requested but if the total of requests exceeds the pool size, all receive nothing (Van Lange et al., 2014a). This choice is often repeated and in some games, after all participants take some of the resource, the pool is replenished at some rate (e.g. 20% of the remaining pool size) before the next round begins.

Among the class of N-person games, we are particularly interested in the *take-some game*. Let us consider the matrix of the take-some game, which displays the payoff to both cooperators and defectors as a function of the number of cooperators, presented in Table 1.1. Payoffs refer to the magnitude of the rewards and/or punishments associated with cooperative and noncooperative behaviors, respectively (Hine, 1990).

Table 1.1

Payoffs of the take-some game.

The "Take Some" Game		
Number of cooperators	Payoffs to defectors	Payoffs to cooperators
3	--	$1.00
2	$2.00	0
1	$1.00	–$1.00
0	0	--

Adapted from "Social Dilemmas," by R. M. Dawes, 1980, *Annual Review of Psychology, 31*, p. 180. Copyright 1980 by Annual Reviews Inc.

Observing this table, we can conclude that in addition to the two-abovementioned inequalities describing N-person games, the take some game has three additional properties (Dawes, 1980). First, the payoff to defectors is bigger as more players cooperate. Second, the payoff to cooperators is bigger as more people cooperate. Third, an individual who defects receives a higher payoff than if he had cooperated. These proprieties yield the payoff functions for cooperating and defecting presented in Figure 1.3. However, the take-some games where participants may take points from a pool that can "replenish itself" at varying intervals and in amounts that depend upon the subjects' restraint, defy a simple mathematical description like the previous.

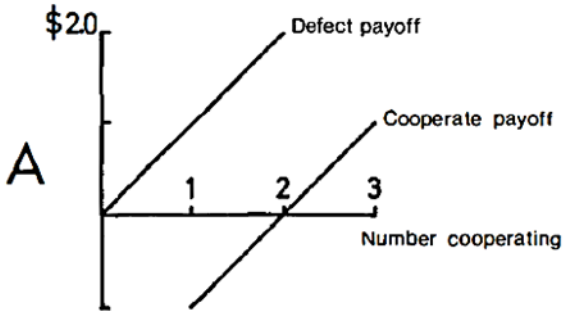

Figure 1.3 Plot of the payoffs for the take-some game. The defection payoff function is above the cooperation function for its entire length and the right extremity of the cooperation function is higher than the left extremity of the defection function. Adapted from "Social Dilemmas," by R. M. Dawes, 1980, *Annual Review of Psychology, 31*, p. 181. Copyright 1980 by Annual Reviews Inc.

By changing these payoffs we observe cooperation and defection rates change as well. Several studies focusing on N-person social dilemmas demonstrated that as we vary the payoffs in the direction of greater individual return for cooperating and lower individual return for defecting, cooperation levels increase (for reviews see Dawes, 1980; Kollock, 1998).

We can increase cooperation by taking the individual profit out of the competitive response, similarly to creating taxes for defecting or bonuses cooperating (Kelley & Grzelak, 1972). By changing the slopes of the payoff functions, we also change the motivational pressures for defection: fear (defecting out of fear the other will defect) and greed (defecting to get a higher payoff) (Komorita, Sweeney, & Kravitz, 1980). However, an extreme payoff can also be a dilemma-nullifier: a considerable increase in the reward for cooperation or in the punishment for defection, extinguishes the dilemma (Dawes, 1980; Gifford & Hine, 1997). In these scenarios, the incentive to defect essentially disappears.

In a recent meta-analysis, rewards and punishments exhibited an equivalent positive effect on cooperation (Balliet, Mulder, & Van Lange, 2011). Additionally, authors observed that: 1) higher costs of incentive promoted cooperation; 2) the system administrating the incentives (centralized vs decentralized) had no effect on cooperation. **Costly incentives** requires subjects have greater costs to provide reward (for cooperation) and to deliver punishments (for noncooperation). The effectiveness of incentives appears to be stronger when the incentives were costly to administer, compared to free. It is plausible that the administration of costly incentives reflects a strong commitment to promote cooperation, rather than simply pursuing self-interest. **Centralization of incentives** relates to who administers the rewards/punishments. Actual participants in the dilemma provide the decentralized incentives whereas centralized incentives are those provided by external sources. No differences in cooperation were observed as a function of centralization.

In conclusion, sanctioning systems offer potential benefits to promote cooperation in take-some games. On the other hand, they may undermine intrinsic motivations for cooperation and interpersonal trust (Kopelman, Weber, & Messick, 2002)

For this project, the dilemma type will be a take-some game, from here forward addressed as a **commons dilemma**. The dilemma here lies in the fact that even though we might want to harvest as much as possible for ourselves, if we do so, the resource will deplete sooner and no one will be able to harvest more. In other words, collective noncooperation leads to a serious threat of depletion of future resources (Van Lange, Liebrand, Messick, & Wilke, 1992). Commons dilemmas can be characterized as social traps, since the behavior that leads to individual benefit in the short-term can lead to long term collective costs (Platt, 1973). Although not specifically defined in even the most influential papers, cooperating is generally expressed by harvesting less and defecting by overharvesting.

Edney, (1979) proposed the simplest experimental version of the commons dilemma in the laboratory. Subjects sat around a table and were instructed not to communicate. At the table's center was a bowl full of nuts and each subject could take as many nuts from the bowl at any time after the start of the trial. At the end of each trial, the number of remaining nuts doubled. However, the maximum number of nuts would not exceed a certain number. This cycle of collecting and replenishing nuts ends when a given time limit is reached or when the players empty the ball. In this version, the bowl represents the resource pool (such as fish in an ocean); the nuts the resource itself; the replenishment cycles are the natural regeneration rates; and taking the nuts is the harvesting behavior.

Why choosing a commons dilemma to look at cooperation? There were four main reasons. First, this N-person game more clearly approximates resource-management problems and the dilemma involved in managing a common resource than the traditional prisoner dilemma (PD) game (Edney & Harper, 1978b).

Secondly, a commons dilemma provides us with a quantitative measure of cooperation. Here, cooperating is measured by how much we harvest, relatively to the resource available and its regeneration rate (Gifford & Hine, 1997). The decision-making is framed in terms of *how much should I harvest?;* instead of *should I cooperate or defect?*. We consider the former approach to be a more ecologically valid measure of cooperation than the qualitative and binary choice of the latter.

Thirdly, we opted by a take-some commons dilemma type due to its decision framing. Resource dilemmas can be framed as **take-some** – *how much should I take from the resource?* - or **leave some** dilemmas – *how much should I leave in the resource?*. It was suggested that group members are more focused on the outcome distribution when deciding how much to take

from the resource than when deciding how much to leave (van Dijk & Wilke, 2000). We opted for the take-some version to assure subjects focused on the outcome distribution.

Finally, the commons also allows for a better operationalization of cooperation. Gifford & Hine, (1997) proposed four basic formulas of cooperation: individual restraint, group restraint, individual efficiency, and group efficiency. These include four main elements: the amount of the resource, the number of harvesters, the size of harvests, and/or the regeneration rate of the resource. Their mathematical definition of cooperation allows comparing cooperation across studies. Furthermore, these formulas are useful to analyze cooperation efficiency, a feature that seems neglected in the literature.

Fate of the commons

How do we behave when faced with commons dilemmas? Hardin, (1968) proposed in his a groundbreaking paper that commons dilemmas will inevitable end in tragedy. To illustrate this, he used the example of overpopulation, although it applies to every commons.

> Picture a pasture open to all. It is to be expected that each herdsman will try to keep as many cattle as possible on the commons. (. . .) As a rational being, each herdsman seeks to maximize his gain. Explicitly or implicitly, more or less consciously, he asks, "What is the utility to me of adding one more animal to my herd?". (Hardin, 1968, pp.1244)

Each herdsman benefits from adding one animal to its heard, increasing his sale profits by one animal. Although one more animal creates additional overgrazing, all herdsmen share this cost. Thus, the rational herdsman concludes he should add another animal to its herd and he keeps adding. Other herdsmen will reach the same conclusion until the pasture is completely destroyed, and no herdsman will be able to feed its cattle. Hence, the *tragedy of the commons*.

For Hardin, this tragedy is certain when there is free access to the commons. In his perspective, the only solution is *mutual coercion mutually agreed upon*. In his view, successful management of a commons requires an external authority that taxes herdsmen to be able to enforce the necessary restrictions to avoid resource extinction.

However, not all commons end in tragedy, as Gifford & Hine, (1997) demonstrate in their paper *Towards Cooperation in a Commons.* If we accept Simon's idea of human docility, it follows some group members will cooperate given this is a culture-transmitted behavior that is adopted without full evaluation. Moreover, several factors other than the mutual coercion mutually agreed upon promote or moderate cooperation in a commons and these are addressed in the section below.

Defining cooperation in a commons

In their paper, Gifford & Hine, (1997) emphasize the difficulty in defining cooperation in a commons. The most groundbreaking papers do not specifically define cooperation and different studies provide dissimilar definitions, such as cooperating as:

1. Taking none of a resource;
2. Taking less of a resource than one customarily does or less than some current norm;
3. Notion of taking a fair share: the amount each harvester should take, relative to the total number of harvesters;
4. Sustainability, efficiency, or conservationism;
5. Harvesters' own assessment of their harvest practices.

These authors suggest that harvest should not be measured as an absolute number of points or resource units taken, but include instead some reference to the size of the resource pool and its regeneration rate. However, how can we measure cooperation reliably in a such a

complex paradigm? These authors propose some mathematical formulas of cooperation for the individual and group level - individual restraint and group restraint – and include measures of efficiency – individual and group efficiency.

However, these measures also have some limitations if their goal is to represent cooperation. Suppose an individual takes too much of a resource early on and in the late rounds, when the pool is in danger of depletion, he takes very little. Individual restraint and efficiency measures may indicate this subject was very cooperative and effective in maintaining the resource in the late rounds, when in fact he is only compensating for his initial greed or competiveness.

Another cooperation index used in the literature is the number of rounds participants play. The sooner the commons ends, less cooperative were the individuals. Nevertheless, this is a gross measure since several groups may finish the resource in the same round with completely different harvesting patterns. An alternative and possibly more interesting measure is the number of points left at the end of each round or the number of points replenished after each round.

What influences cooperation in a commons?

Several variables influence how much we cooperate in commons dilemmas and we can distinguish two categories: individual and situational factors (Kopelman et al., 2002). The following section focuses on five individual variables and several situational ones, culminating with resource crisis.

Individual variables

Until now, five individual variables were recognized to influence cooperation in a commons: previous experience with these dilemmas, culture, gender, expectations about others and one's social value orientation (SVO).

a. Previous dilemma experience

It appears that substantial previous experience with one-shot anonymous laboratory games undermines our intuitive and more automatic response of cooperation (Rand et al., 2014).

Cooperative behavior in one-shot PD games is highly dependent on two individual characteristics - altruism and reasoning ability – with altruists being more cooperative and high reasoning individuals being more competitive (Barreda-Tarrazona, Jaramillo-Gutiérrez, Pavan, & Sabater-Grande, 2017). Although altruism and reasoning ability significantly affect behavior in single encounters, it appears that previous experience with the repeated PD game takes over these two individual characteristics in explaining cooperative behavior. With experience in repeated PD games, all players (high and low altruism vs high and low reasoning ability) reached similar levels of sustained cooperation in the repeated game.

Not surprisingly, previous experience with commons dilemmas improves resource management (Gifford & Hine, 1997; Hine, 1990). The effect of prior experience in commons dilemmas was studied by manipulating group size and type of experience – either group or individual experience[2] (Allison & Messick, 1985). Results indicate previous individual experience improved subsequent group performance more than previous group experience. Overall, groups with individual experienced members kept the resource active much longer

[2] Subjects either managed the resource alone (individual experience) or managed the resource with a group (group experience).

and harvested less than group experienced or no experience members. Large groups seemed to benefit more from previous experience (particularly individual) than smaller groups.

In general, it seems that experience with a particular game type leads to better performance on that game, which means defecting in one-shot interactions and, generally, cooperating in repeated games. In one-shot games, regardless of what the adversary choses, the best strategy is to defect. If one player is selfless, the most profitable action for the other one is to exploit the good faith being selfish. On the other hand, if one player is selfish, the best action for the opponent is to be selfish too, minimizing the damage. Interestingly, this does not happen in the real world and we often cooperate in one-shot games (e.g. Rand, 2016; Rand et al., 2014; Rand & Nowak, 2013). In iterated/repeated games, the "best strategy" is more difficult to define. Currently, the best strategy in PD games Pavlov, also known as, win-stay, loose-shift (Nowak & Sigmund, 1993). It starts with a cooperative move and then, the player repeats the last action if it was profitable, otherwise it changes actions. In commons dilemma there is no concise definition of an optimal strategy since the behavior of other group members is a quantitative rather than qualitative choice.

b. Culture

A few studies on the influence of culture on cooperative behavior in social dilemmas have been conducted, comparing individual and collective cultures. In general, collective cultures are more cooperative in N-person games but more punishing when there is the possibility of administering sanctions.

Liebrand & van Run, (1985) compared cooperative behavior of American and Dutch subjects in a commons dilemma. Although Americans were expected to display relatively more competitive social motives and Dutch subjects relatively more cooperative ones, no differences in social motives or cooperative behavior were observed.

However, a subsequent study compared the behavior in a commons dilemma of American (individualistic culture) with the Vietnamese (extremely collectivist culture) (Parks & Vu, 1994). Americans cooperated at typical levels in most social dilemma studies while the Vietnamese cooperated at an exceptionally high rate, even when playing against an extremely competitive algorithm.

A known way to induce cooperation in social dilemmas is through rewarding cooperators and punishing of non-cooperators (see Balliet, Mulder, & Van Lange, 2011 for a meta-analysis). These authors analyzed data from 27 countries in their meta-analysis, revealing that the impact of incentives on cooperation varies significantly between countries. Punishment had a positive effect on cooperation in several countries (e.g., Australia, Japan, United States) and enhanced group efficiency but tended to have no impact on cooperation in Russian samples, for example, reducing group profits.

Another culture dependent behavior is antisocial punishment, which consists in punishing cooperators (Herrmann, Thöni, & Gächter, 2008). For example, non-cooperators who were punished in the past for their behavior might retaliate against cooperators, since they are the most likely to have punish them. These authors compared several cultures around the world in public good experiments with and without punishment. They found evidence of stronger antisocial punishment in collectivist societies than individualistic ones, possibly because the former are more inclined to perceive other participants as outgroup[3] members. Further analysis of these results revealed that in the absence of punishment, individual variation is much more important than cultural variation in explaining cooperation, with the opposite being true in the presence of punishment (Gächter, Herrmann, & Thöni, 2010).

[3] Generally, an outgroup is a group which an individual does not identify with (different race, gender, age, religion, etc.). but can also be elicited based on trivial criteria such as aesthetic preference or random assignment (Tajfel, 1974).

c. Gender

A recent meta-analytic review verified there are no significant sex differences in cooperation in social dilemmas (Balliet, Li, Macfarlan, & Van Vugt, 2011). However, the association between sex and cooperation is moderated by the social context. The analysis revealed that men cooperate more than women in same-sex interactions but women are the more cooperative gender in mix-sex interactions. Additionally, as the dilemma continues for several rounds, men become increasingly more cooperative than women. Finally, sex differences in cooperation are unaffected by group size and the type of dilemma (prisoner's dilemma, public goods or commons dilemma).

d. Social Value Orientation

Social motives or one's **social value orientation** (SVO) is currently regarded as a stable personality trait which reflects how people evaluate outcomes for self and others, determining cooperative motives, strategies, and choice behavior (Bogaert, Boone, & Declerck, 2008).

McClintock, (1972) identified four social orientation types: 1) competition – the motivation is to maximize relative gains, the difference between one's outcome and that of the other; 2) individualism, where the motivation is to maximize one's own gains; 3) cooperation – the motivation is to maximize joint gain; 4) and altruism, where the motivation is to maximize the other parties' gains. Therefore, according to this classification we should consider SVO as a spectrum from competition to altruism, as presented in Figure 1.4.

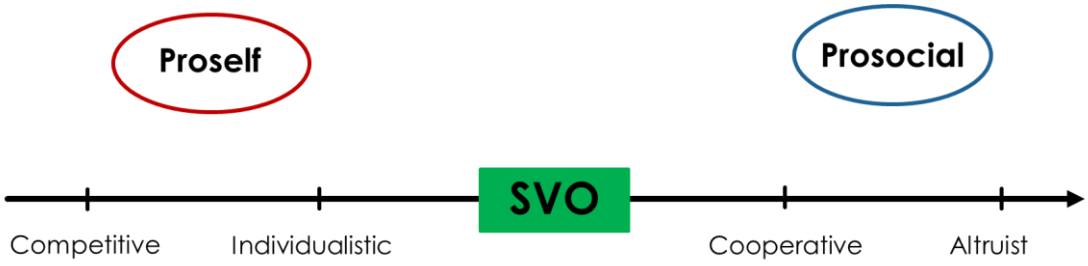

Figure 1.4 Social Value Orientation Spectrum.

Social value orientation seems to have a weak but reliable relationship with gender: the percentage of prosocials (cooperators) is slightly higher among women than men, while that of proselves (individualists and competitors) is higher among men (Kopelman et al., 2002).

Literature suggests people with different social values select different behavioral strategies in social dilemmas (Bogaert et al., 2008). Prosocials are expected to be more sensitive to trustworthiness, which increases their expectation of reciprocated cooperation and reduces the fear of being exploited. Proselves, on the other hand, need explicit incentives to align the goal of pursuing their own best interest with the goal of cooperating with the collective.

More than 82 studies have been conducted to assess the relationship between SVO and cooperation in social dilemmas (Balliet, Parks, & Joireman, 2009) but we will solely focus on the ones addressing SVO in iterated commons dilemmas. Not surprisingly, prosocials are more cooperative than proselves, with the latter harvesting significantly more resources than the former (e.g. Balliet et al., 2009; Budescu, Au, & Chen, 1997; Joireman, Posey, Truelove, & Parks, 2009; Kramer, McClintock, & Messick, 1986; Liebrand, 1984; Liebrand & van Run, 1985; Loomis, Samuelson, & Sell, 1995; Parks, 1994; Roch & Samuelson, 1997).

Liebrand, (1984), observed consistent differences between the four classes of social motivation in the amount of resources taken for self. Competitive subjects harvested the most, individualists harvested a little less but still above average. Cooperative and altruistic subjects took the smallest amounts.

In a subsequent study, this relationship between SVO and cooperation in a commons was analyzed in two different cultures: American (more competitive) and Dutch (more cooperative) (Liebrand & van Run, 1985). Americans were expected to have a greater percentage of proself individuals but no differences in the distribution of social motives neither in the amount of resources taken to self were observed when comparing both cultures.

However, in both groups competitive subjects harvested the most, next came individualistic subjects, cooperative subjects took even less and altruistic subjects took the least. Finally, Budescu et al., (1997), again observed that the points requested were systematically related to the players' social values. Competitive subjects harvested the most (mean points harvested = 145.4), followed by individualistic (100.3) and then cooperative subjects (96.2), and with altruists harvesting the least (87.4).

This decreasing pattern in harvest behavior when we move towards the prosocial end of the SVO spectrum supports the notion of social motives as a continuum. However, in most studies the only reported differences of social motives in cooperative behavior are between prosocials and proselves (e.g. de Kwaadsteniet, van Dijk, Wit, & de Cremer, 2006; Kramer, McClintock, & Messick, 1986; Roch & Samuelson, 1997). More studies on the relationship of SVO and cooperation in commons dilemmas were not included above because SVO was not the variable of interest. Nevertheless, those findings are mentioned throughout this section and, as we shall see, the behavior of prosocials and proselves differs under several conditions.

To summarize, prosocials and proselves differ in three dimensions in commons dilemmas: cooperative behavior, rationality and intelligence perception (Kopelman et al., 2002). As presented above, prosocials are more likely to cooperate in commons dilemmas. Prosocials tend to view rationality in collective terms whereas proselves tend to view it in individual terms. Moreover, prosocials tend to see cooperation as moral and of competition as immoral, while proselves tend to consider competition as more effective. Finally, both prosocials and proselves believe their own strategy to be the more intelligent.

e. Expectations about others

Expectations about the behavior of other group members may be determinant in each individual's decision to cooperate or defect (Williams, Jackson, & Karau, 1995). One's choices

in such dilemmas not only reflect beliefs about others, but also affect these beliefs (Dawes, McTavish, and Shaklee, 1977). That is, expectations about others influence the subjects' decision to cooperate or defect and vice versa.

Interestingly, different expectations about others can lead to defection, which further obscures the interpretation of behavior in social dilemmas (Dawes, 1980). A subject can defect because he/she believes others will not defect, aiming to receive a big payoff; or he/she can defect on the belief others will defect, in order to avoid a big loss. In the former, the motive behind defecting is greed and in the latter, the reason is fear.

Some studies use the concept of trust to infer expectations of others' behaviors and typically observe a strong positive relationship between trust and cooperative behavior (Williams, Jackson, & Karau, 1995). That is, trusting others will cooperate increases the likelihood that the subject cooperates himself.

More interestingly, several studies suggest that one's own social value orientation influences expectations about others (Dawes, McTavish, & Shaklee, 1977; Kelley & Stahelski, 1970; Kramer et al., 1986; Kuhlman & Wimberley, 1976; Liebrand, 1984; Maki & McClintock, 1983)

Kelley & Stahelski, (1970) propose that proselves expect others to be homogeneously competitive, while prosocials have no consistent expectation. This happens because proselves elicit competition from both prosocials and proselves. Since prosocials resort to competition with proselves and use cooperation with other prosocials, they are more heterogeneous in their expectations. This differential pattern in expectations according to one's own SVO is called the triangle hypothesis.

Kuhlman & Wimberly, (1976), proposed an alternative justification for the observed differences in expectations, although both explanations are not mutually exclusive. Their

observations suggest that subjects' expectations about others are a function of their own motivation, with subjects expecting others to be in their "motivational neighborhood".

Since the above studies used the prisoner's dilemma game, we should also explore the role of SVO on expectations in commons dilemma. As anticipated, prosocials expect more cooperation from others than do proselves (Kramer, McClintock, & Messick, 1986) and proselves expect more defection, predicting approximately four times as much defection than prosocials (Dawes et al., 1977). In accordance to the "motivational neighborhood" explanation, Kramer et al., (1986) propose that individuals use their own social values as base-rate information when making prediction about others' values and behaviors. They also suggest this phenomenon might be a reflection of the egocentric attribution bias – information about the self is more readily available and easier to retrieve (Ross & Sicoly, 1979)

Contrarily to this egocentric attribution bias, Liebrand, (1984) observed that competitive subjects expected others to take fewer resources than they intended to themselves; and altruistic subjects expected others to take more resources than they intended to themselves. In two experiments, authors found both the egocentric attribution hypothesis and the triangle hypothesis were too restrictive to explain the pattern of results. However, these results should be considered separately, since expectations about others were evaluated after feedback of how others behaved.

Subjects with different social motives not only differ in their expectations of others' behavior but also vary in their predictive accuracy (Maki & McClintock, 1983). In this study, subjects observed "choosers" (preprogrammed players with an altruistic, cooperative, individualistic, or competitive SVO) select between self and other outcome alternatives. Results confirmed that subjects' own SVO affected their abilities to predict the different choosers' behaviors. Cooperative and individualistic subjects displayed increased predictive accuracy, regardless of the choosers' SVO, while altruistic and competitive subjects varied

their predictive accuracy as a function of the choosers' orientation. Cooperative subjects proved to be the most accurate predictors on average (82%), followed by individualistic (72%), altruistic (65%), and finally competitive subjects (64%). Authors suggest that altruists and competitors may be less attentive and less motivated to think about the others' behavior because it has little to no implication for their strategy. Regardless of playing with an altruist, cooperator, individualist or competitor, altruists respond with cooperation (maximizing the others' gain) and competitors with competition. The prior pattern of findings does not support the egocentric attribution hypothesis since subjects did not systematically predict the choosers' behavior would be consistent with their own SVO. Instead, the pattern of results for cooperative and competitive subjects resembled the triangle effect observed by Kelley & Stahelski, (1970).

Situational variables

The situational variables influencing cooperation in a commons dilemma are related to the task structure and to the subjects' perception. Concerning the former, we can further divide it into two categories: social and decision structure. Social structure includes the power and status of group members, ability to communicate between themselves and group size as well. Decision structure relates to the resource status (environmental uncertainty, territoriality and resource use). As to the perceptual factors modulating cooperation, we have the way the problem is framed; the causes of what is happening with the resource; providing information about strategies; and degree of identification with other group members.

Perception

a. Frames

Framing, in the study of decision-making, concerns the ways in which outcomes, options, and actions are described (Kopelman et al., 2002). The manner the social dilemma is framed clearly influences cooperation.

First, framing the outcomes of the dilemma as gains or losses. When people contribute or give money, they experience a loss (public-goods dilemma); and when they harvest from a resource they experience a gain (commons dilemma). Subjects with a cooperative SVO, cooperate more in loss-framed games than in gain-framed ones, while the reverse tends to be true for individualists and competitors (De Dreu & McCusker, 1997).

Second, framing games as entrepreneurial or social exchange. This was studied by introducing subjects with a cooperative vs entrepreneurial reading material followed by a public goods game. As predicted, people made more cooperative choices when the task was framed as a social exchange study than as a business transaction study (Elliott, Hayward, & Canon, 1998).

Finally, framing the decision problem in terms of taking (commons dilemma) or giving (public goods). When the decision problem is framed as taking vs giving, we observe differences in choice behavior (Brewer & Kramer, 1986; Fleishman, 1988) or in the willingness to appoint a leader (Rutte, Wilke, & Messick, 1987).

In commons and public goods dilemmas participants are either focused on what they end up with (take or keep) or on what they contribute (give or leave) (van Dijk & Wilke, 2000). These authors suggest group members are less focused on the consequences of their actions for the final outcome distribution when deciding how much to contribute (give or leave) than when deciding how much they will end up with (take or keep). Subjects are more motivated to minimize differences in final outcomes in commons dilemmas because distributing outcomes

equally among members is more salient; and in public goods dilemmas, providing enough to provide the public good is more salient (van Dijk & Wilke, 1995). This is consistent with the phrasing effect, first described by Harris & Joyce, (1980), who observed subjects were more concerned with distributing outcomes equally if they were focused on outcomes instead of expenses.

b. Causes

People will only try to solve social dilemmas if they believe it is their responsibility and if they place causal agency on themselves (Kopelman et al., 2002). Additionally, how people perceive which is causing the situation will influence how much of a resource they harvest. This relates to the causes of the priority position regarding access to a shared resource, scarcity/abundance of the resource and preferences for appointing a leader.

Regarding the priority position in the access to a shared resource, there is a known "position effect", where the first ones to harvest have a distinct advantage, making larger requests than the players who come later (e.g. Budescu, Au, & Chen, 1997; Budescu, Rapoport, & Suleiman, 1995; Budescu, Suleiman, & Rapoport, 1995; Suleiman, Budescu, & Rapoport, 1994). When there is a reasonable explanation for the privileged position – participants somehow "earned the right" to be the first – we observe they take more from the resource than participants whose privilege position is perceived as more unfair or random (Samuelson & Allison, 1994).

The cause of scarcity or abundance of the resource pool can be attributed either to other group members or to nature. In a water shortage scenario in California, people who respected the limits of water usage believed the shortage had natural causes whereas those who exceeded their limit believed the shortage was people-induced (Talarowski, 1982). Additionally, when there is full knowledge about pool size, the shortage or abundance is attributed to other people

but is attributed to chance or nature when the pool size is invisible (Rutte, Wilke, & Messick, 1987).

Lastly, the perceived cause of a resource crisis (resource depletion) influences the preference for a structural solution – designating a leader. When this prior failure was attributed to task difficulty, 57% of the subjects favored appointing a leader; and when the failure was attributed to personal greed, only 30% chose having a leader (Samuelson, 1991).

c. Social identity

Relatively minor changes in the social environment can induce major changes in decision making, such as the decision maker seeing himself/herself as an individual or as a part of a group (Dawes & Messick, 2000). This social identity can either be elicited by naturally occurring groups, such as individuals from the same country, religion, etc., or through a social identity manipulation.

Baird, (1982) observed that subjects who shared a monetary reward before doing a commons dilemma task (collective identity) were able to preserve the resource more effectively and earned more money than groups that had not shared a reward earlier (individual identity).

Later, Kramer & Brewer, (1984) observed that a collective social identity promoted cooperation in an endangered commons, even when the basis of this group identity is minimal (Tajfel, 1970, 1974). Social identity was either manipulated by varying the "common fate"[4] of group members (collective vs individual); or naturally occurring social categories were used (age and student status). When faced with an endangered commons, individuals were more likely to exhibit self-restraint when the collective identity was salient. In the individual condition, mean harvest per trial was always above optimum level to sustain the resource.

[4] in the collective condition, subjects were told there would be one lottery to determine the monetary value of points for all players; and in the individual condition that there was one lottery for each player.

Contrarily, when collective identity was salient, the mean harvest per trial reached optimum level (and even suboptimal) in the depletion conditions.

Using the same "common fate" manipulation (collective vs individual conditions), Brewer & Kramer, (1986) replicated the previous finding and further demonstrated the power of social identity. The social identity manipulation only had an effect when there was already a severe depletion of the common resource. Self-restraint was higher in the collective identity than in the individual identity group, especially when the group size was large. Notably, this occurred despite expectations of reciprocity and overall low perception of self-efficacy in the large group collective condition.

Simpson, (2006) reviews two explanations regarding the effects of social identity on cooperation and proposes social identity leads group members to maximize group outcomes and minimize group inequalities, reducing the motivational greed to receive a big payoff while the fear of being exploited remains unaffected.

d. Informing about strategies

Not surprisingly, studies on the relation between providing information about strategies and resource management efficiency yielded positive results (Hine, 1990).

Stern, (1976) manipulated the type of educational strategy given to participants: some information vs full information. The former informed about long-range consequences and the latter presented detailed information about the long-term effects of consumption. While "some information" had no effect, "full information" increased conservation and extended the lifetime of available resources.

Rapoport, (1988) replicated these results, comparing minimal and full instructions, the latter including the disclosure of the collective rational strategy. Full instructions had a small

positive effect, raising the level of cooperation at several indices but very few groups actually adopted the collective rational strategy.

Surprisingly, giving some information about the decision problem may be more effective than providing a "good strategy" (Edney & Harper, 1978b). In this experiment there were three levels of information: no information (basic game instructions); information about social trap characteristics; and effective strategy. Unexpectedly, groups provided with an effective strategy performed as poorly as subjects given no information did. However, groups given information about the social trap performed significantly better than the previous two, having significantly more points, rounds played and pool replenishments. One explanation is that even after learning about the benefits of cooperation, defection remains the dominant strategy for each individual (Hine, 1990).

While Edney & Harper, (1978) informed subjects on a good strategy, Schroeder, Jensen, Reed, Sullivan, & Schwab, (1983) actually informed them about the optimal strategy. When they did not inform subjects about the optimal strategy, participants observed and sometimes adopted the behavior of other group members and this social conformity led to suboptimal results. However, when a credible source provided the optimal strategy, subjects reduced their tendency to guide their behavior by the actions of others.

e. Moral suasion

Limited processing theory suggests that eliciting feelings of altruism, morality, and responsibility among group members should help to preserve the commons by drawing their attention away from the payoff structure (Hine, 1990)

Before beginning a commons dilemma task, all subjects were instructed the goal was to get as many points as possible (control group) and half read an additional moral message (moral suasion group) suggesting that individuals "do unto others as you would have them do

unto you" (Edney & Bell, 1983 cited in Martichuski & Bell, 1991). Authors observed the management of the commons of the moral suasion group improved in comparison to the control group. Using the same "golden rule" manipulation, Martichuski & Bell, (1990) replicated these findings. Subjects in the moral suasion group increased the overall harvest and the life of the commons in comparison to controls.

Not only can we promote cooperation through a prior "moral message", but we can also encourage competition by altering the content of this message (Sattler & Kerr, 1991). In this study, subjects heard one of three audiotaped messages before performing a commons dilemma task: 1) moral message – encouraged cooperation by indicating it is a good, moral, and socially approved behavior; 2) power message – induced defection by indicating that it can lead to power, control, and domination of the game; 3) control message. In comparison with subjects in the control condition, subjects hearing the moral message were significantly less competitive, and subjects hearing the power message were significantly more competitive.

Task structure

a. Social structure

i. Power, status and leadership

The power and status of individuals in a commons dilemma can have a significant effect on how individuals and their actions are perceived (Kopelman et al., 2002). In a commons, power can be defined as a privileged position in terms of access or management of a common resource. Examples are some people having access to the resource first; some being able to take more items from the resource than others; deciding how to distribute the resources among group members, attributing rewards and penalties to other group members, etc.

When an individual betrays expectations in a commons dilemma, the justification he offers for that behavior is perceived differently, according to his/her level of power and status

(Massey, Freeman, & Zelditch, 1997). Authors manipulated the power and status (higher or equal) of a preprogrammed group member and the justifications he gave for his behavior (valid, ambiguous or invalid). In general, authors observed that when individuals had a higher status (e.g. Ph.D. in resource management) and/or higher power (could administrate rewards and penalties at the end of each round) a valid or ambiguous justification for the offending acts was perceived as more acceptable by other group members. However, if the justification was invalid, the higher status became a liability.

When there are such power imbalances, the dilemma is said to be asymmetric and, in these cases, there is a stronger tendency towards overharvesting (Mannix, 1993; Wade-Benzoni, Tenbrunsel, & Bazerman, 1996). For example, Mannix, (1993) observed that groups with power imbalances made less efficient use of the resources; were more likely to distribute resources to a subset of the group; and took more effort to reach agreements on resource distributions. However, some forms of communication, such as discussion or voting, between group members can counteract this effect (Kopelman et al., 2002).

Interestingly, the effects of asymmetry are dependent on the dilemma type (van Dijk & Wilke, 1995). In public goods games, subjects tend to guide their behavior by the proportionality rule: they consider it fair if group members contribute in proportion to their endowments (van Dijk & Grodzka, 1992) or interest position (van Dijk & Wilke, 1993). For example, members with twice as much endowments should contribute twice as much and members having twice as much interest in the public good should contribute twice as much. On the other hand, in commons dilemmas we observe subjects have a tendency to base their decisions on the equal final outcomes rule (Samuelson & Messick, 1986). These authors compared high access vs low access members, where the former could take three times more resource units per trial than latter. High access members took only slightly more than low

access members, suggesting that subjects may have based their decisions on the equal outcomes rule.

Wit & Wilke, (1990) examined the role of who presented rewards and punishments in a social dilemma (government vs parent company), and to whom they were presented (undergraduates vs managers). For undergraduates, considered “lay people”, there was no difference between the effectiveness of rewards or punishments on their choices, regardless of which entity presented them. In contrast, for managers, who are more knowledgeable, rewards provided by the parent company were highly effective, while those supplied by the government were counterproductive.

Under certain conditions, group members willingly endow authorities with additional control over the resource or opt to appoint a leader. Namely when they have failed to manage a resource efficiently (Messick et al., 1983; Samuelson, 1991) and when inequalities in harvesting outcomes emerge (Rutte & Wilke, 1984; Samuelson & Messick, 1986). Not surprisingly, group members will endorse leaders when they are successful in maintaining the common resource (Wit, Wilke, & Van Dijk, 1989; Wit & Wilke, 1988).

Samuelson & Messick, (1986) created a power imbalance by varying access to a resource pool (high vs low), with high access members being able to take triple as much. They also manipulated the level of variance in others' harvests (low and high); and level of resource use (optimal and overuse). As expected, high access members harvested more than low access subjects. After, subjects voted on the possibility of a structural change in second session. Only high access subjects voted more strongly for electing a group leader or dividing the commons in equal territories, when they experienced resource overuse in the first session, with high variance in others’ harvests,

Rutte & Wilke, (1984) replicated this effect, with more subjects in the overuse (compared to optimal and underuse) and in high variance (compared to low variance condition)

voting to appoint a leader. Additionally, when subjects acted as leaders they reduced their harvests and allocated outcomes equitably to group members. This goes in line with Messick et al., (1983) findings, where leaders in a second session of the commons harvested much less than as common group members in a first session, and did so very close to the optimum level.

ii. Communication

A meta-analytic review reported a large positive effect of communication on cooperation in social dilemmas (Balliet, 2010). This effect was moderated by two variables: type of communication, with a stronger effect of face-to-face discussion compared to written messages; and group size, with a stronger effect in larger groups. No differences were observed for communication that occurred before or during iterated dilemmas. Most of the dilemmas comprised in this meta-analysis were give-some or PD games, with only three studies using a commons dilemma.

Dawes et al., (1977) used a one shot version of a commons dilemma with four communication conditions: no communication, irrelevant communication, relevant communication, and relevant communication plus roll call (nonbinding declaration of intended decision). Results demonstrate that defection was significantly higher in the no-communication and irrelevant-communication conditions than in relevant-communication and relevant-communication plus roll call conditions.

Through a content analysis of group discussion, Brechner, (1977) observed that subjects talked more frequently about one's own progress in the game and asked about others' progress (in terms of total points obtained). The second most frequent type of statements were requests to stop harvesting when pool neared depletion; and, in third place came strategy suggestions. He also replicated the beneficial effect of communication on cooperation in a commons.

Finally, communication seems to have the same positive effect on cooperation, regardless of subjects' social value orientation (Liebrand, 1984). As expected, when communication was allowed, significantly fewer sources were taken for self and, perhaps surprisingly, this effect did not differ across individuals with different social motives.

Why does communication promote cooperation? It was suggested that group discussion increases cooperation possibly because: 1) it enhances group identity or solidarity; 2) it elicits commitments to cooperate (Kopelman et al., 2002). Two studies manipulating the presence/absence of communication demonstrate group identity alone is insufficient to account for the communication effect and suggest the explanation lies in the commitment to cooperate (Kerr & Kaufman-Gilliland, 1994) or in the perceived consensus to cooperate (Bouas & Komorita, 1996). Another possibility is that discussion decreases egocentric biases (Wade-Benzoni, Tenbrunsel, & Bazerman, 1996).

iii. Group size

Several empirical studies using the N-person PD, support that cooperation is an inverse function of group size (Dawes, 1980; Komorita et al., 1980; Marwell & Schmitt, 1972). In other N-person games, group size has a different impact on cooperation according to the framing of the dilemma (Brewer & Kramer, 1986). Social dilemmas framed as public goods (giving) seem to be more sensitive to group size effects than those framed as commons dilemmas (taking)

When comparing different sized groups we observe differences in cooperation and in the impact of what happened in the previous trial (Hamburger, Guyer, & Fox, 1975). In a take-some task comparing three and seven person groups, the smaller-sized group was markedly more cooperative than the larger group. Moreover, in small groups, the probability of an individual cooperating in a given trial is little affected by the number of players that cooperated

in the previous trial. In larger groups, however, authors observed this probability of cooperation in a given trial actually decreases as more people cooperated in the previous trials. This finding suggests that members of the larger group experience deindividuation, first described by Festinger, Pepitone, & Newcomb, (1952). That is, the effect of a crowd or group on an individual's behavior that often results in a loss of self-identity, which can encourage aggression or deviations from social acceptable behaviors (Diener, 1989).

In sum, small groups tend to be more cooperative than larger groups. Possible causes are larger groups are more likely to contain noncooperative persons (Kelley & Stahelski, 1970); the communication of intentions and influence through behavior becomes less effective with increasing group size (Bonacich, Shure, Kahan, & Meeker, 1976); and the is a lower sense of perceived individual and collective self-efficacy in larger groups (Kerr, 1989). Additionally, larger groups are associated with deindividuation, social loafing[5], diffusion of responsibility, "big pool illusion" and smaller payoffs for cooperating (Hine, 1990). For this latter reason, the relation between cooperation and group size may be positive or negative depending on how individual and group payoffs are affected by variations in group size (Bonacich et al., 1976).

iv. Choices public vs private

Literature on the effect of anonymity in social dilemmas has yielded inconsistent results, with some studies finding a positive effect (Dawes, 1980) and others a negative or even no effect at all (Williams et al., 1995).

Only one commons dilemma study directly addressed this issue (Jorgenson & Papciak, 1981). Identifiability was manipulated by the use of the name tags and feedback about the choices of each player. Additionally, authors also manipulated the possibility of communication and resource feedback. They observed that groups in the high identifiability

[5] tendency for individuals to expend less effort when working collectively than when working individually (Karau & Williams, 1993).

condition harvested more money and maintained the commons longer only when they were not allowed to communicate and no resource feedback was given. This reinforces the general idea that identifiability increases cooperation, adding it only occurs under certain conditions.

Williams et al., (1995) suggested that the role of identifiability on cooperation may depend on ambiguity of social desirable behaviors, salience of different behavioral goals or differences in the operationalization of identifiability.

b. Decision structure

i. Environmental uncertainty

Uncertainty tends to reduce cooperation in commons dilemmas, although not always (Kopelman et al., 2002). There are three levels of environmental uncertainty: resource visibility, pool regeneration rate and number of trials.

Complete invisibility of resources leads to early destruction of the pool through overharvesting (Cass & Edney, 1978). Pool size uncertainty is associated with significant increases in individual requests and decreases group efficiency (Budescu, Suleiman, et al., 1995; Gustafsson, Biel, & Gärling, 1999; Hine & Gifford, 1996). As uncertainty about the pool size increases, subjects tend to overestimate the pool size (Budescu, Rapoport, & Suleiman, 1990). This "overestimation" may be a justification for their overharvesting behavior (Kopelman et al., 2002). Like the diffusion of social responsibility in large groups (e.g. Latané & Darley, 1968), uncertainty also may act to diffuse personal accountability. Interestingly, subjects' SVO influences harvest behavior under conditions of high but not low uncertainty, with prosocials reducing their harvests but not proselves (de Kwaadsteniet et al., 2006; Roch & Samuelson, 1997).

Uncertainty regarding the regeneration rate of the pool also produces significant declines in individual restraint and group efficiency (Hine & Gifford, 1996). Finally,

uncertainty about the number of trials can actually have the opposite effect. A consistent finding in the gaming literature is that cooperation drops off as the end of the interaction draws near (Kopelman et al., 2002). This is called the "end-game effect": in finite games, cooperation often starts high and declines as the number of rounds increases, reaching its minimum towards the end of the game (Bar-El & Tobol, 2013).

ii. Territorialization

The analysis of five studies on the privatization of the commons – dividing the resource into individually managed territories – demonstrated it improves resource management efficiency (Hine, 1990). However, territorial division is considered a dilemma nullifier, that is, it erases the dilemma because only one harvester takes resources from each sub-territory (Gifford & Hine, 1997). Here, cooperation with others no longer exists and we are only evaluating if subjects comprehend that one must harvest approximately at the resource regeneration rate.

Cass & Edney, (1978) manipulated territorial division and resource visibility. Dividing the commons in individual territories significantly improved resource management, increasing the supply (points left), production (points replenished), and the harvest. A combination of visibility of resources and territorial division resulted in near optimum harvesting. However, territories without resource visibility actually produced a non-optimal overcaution in harvesting. Post-experimental questionnaires revealed that in this system of territories, subjects felt more in control and more personally responsible.

Martichuski & Bell, (1991) observed that privatization of the resource pool was the most effective in maximizing total harvest, extending the life of the commons and protecting the commons from ruin. Interestingly, when the resource was divided into private territories, neither rewards nor punishments helped the management of the commons.

iii. Resource overuse and crisis

Another variable that influences cooperation is whether the resource is being overused, that is, if the subjects' harvests are too high and the resource is rapidly diminishing (Messick et al., 1983).

When resources are used efficiently there is little pressure upon individuals to modify their behavior (Kramer et al., 1986). However, when faced with a resource crisis, subjects have conflicting pressures regarding their harvest behavior. On the one hand, they can increase their harvests because they conform to the overharvesting behavior of other subjects or because of their urge to get all they can before the resource disappears – "getting while the getting is still good" (Kramer et al., 1986; Messick et al., 1983). On the other hand, they can decrease their harvests to compensate the resource overuse, due to their desire to maintain the pool. Studies presented below demonstrate that: trust in others, culture, social value orientation and information moderate harvest behavior under conditions of resource overuse.

Messick et al., (1983) manipulated subjects' perception of the resource use: underuse, optimal use or overuse; and homogeneity of harvesting behavior: low variance (others took relatively similar harvests) or high variance (others' harvests differed greatly). They also included a measure of **trust in others** by asking subjects how much they expected other members to reciprocate restraint in harvesting. Authors observed that in the resource underuse and optimal use conditions, regardless of the level of prior trust, harvest behavior tended to increase over time. In the resource overuse condition, trust moderated subjects' behavior. "Low trust" subjects (who did not expect others to reciprocate restraint) tended to increase the size of their harvests over time. Conversely, "high trust" subjects reduced their harvests as if to preserve the pool, despite knowing others were not restricting their harvests.

Brann & Foddy, (1987) replicated this moderating effect of trust under resource overuse in a subsequent study. The consumption rate of "low trusters" was unaffected by the rate at

which the resource deteriorated. “High trusters” consumed more than “low trusters” when resource deterioration was minimal, but significantly less than “low trusters” under conditions of rapid deterioration.

Samuelson, Messick, Rutte, & Wilke, (1984) replicated some of these findings using a similar design to Messick et al., (1983). Additionally, they looked into the impact of **culture** by comparing Americans and Dutch subjects. They observed cultural differences under resource overuse, when there was heterogeneity in the harvests of group members. Americans further exploited the resource, possibly because there was no group norm. Dutch subjects on the other hand, did not increase their harvests when faced with this heterogeneity, not using it as excuse to promote their own interest. These results are even more interesting in light of the findings of Liebrand & van Run, (1985), that compared American and Dutch subjects but found no cultural differences neither in the distribution of social motives nor in the amount of resources taken for self in the social dilemma game. It seems that culture differences between Americans and Dutch only emerge in such paradigms under extreme conditions, such as resource overuse.

Social value orientation (SVO) when the resource is being overused is also predictive of harvest behavior. When the resource is close to depletion, prosocials respond with greater self-restraint than proselves (Joireman et al., 2009; Kramer et al., 1986; Loomis et al., 1995). The lack of reciprocation of self-restraint does not cause prosocials to abandon their own efforts to preserve the pool, which supports that social values reflect individual motives and not merely strategic concerns (Kramer et al., 1986). In contrast, proselves did not adjust their behavior when faced with rapid depletion of the pool, taking significantly more for themselves than prosocials. Under conditions of sustained pool use, the behavior of prosocials and proselves was similar.

Nevertheless, when there is noise present under resource overuse, prosocials start acting as proselves (Brucks & Van Lange, 2007). In this experiment, noise was introduced by informing participants that from time to time, the computer would take an additional point or two from the pool. Thus, the collective harvest was *noisy* in the sense that it did not necessarily represent the sum of the harvests made by all players. When the resource was close to depletion and noise was absent, prosocials exhibited greater self-restraint than proselves, replicating the findings of Kramer, McClintock, & Messick, (1986). However, when the resource was in danger of depletion and noise was present, prosocials radically shifted their behavior from careful conservation of a scarce resource to overusing the available resources. While the consumption of proselves did not vary much across conditions, prosocials consumption varied strongly across conditions.

Another factor that influences cooperation when the resource is overused relates to **information**. Loomis et al., (1995) provided subjects with different levels of feedback regarding the resource status: no information; categorical information (good, fair or poor resource status; or specific information (how many items left in pool). In the early trials there was no differences in harvest behavior across information conditions. However, as the pool became depleted (later trials), subjects provided with categorical information decreased their requests by a greater amount than did subjects provided specific information or no information. This was surprising, since authors expected the specific information group would be the most restrained. However, they suggest that detailed information on a declining resource can lead to the conclusion that others are continuing to exploit the resource and induce subjects to do the same, instead of reducing their harvests. This explanation is congruent with the findings of Messick et al., (1983).

Not only information content matters, but timing as well (Joireman et al., 2009). Authors investigated how decision makers would react to repeated warnings about a depleting

resource about which they had little to no knowledge. Initial warnings (trial 12) were most effective than subsequent warnings (trials 16 and 22) and warnings were more effective when others' harvests were small. Additionally, harvests were reduced when the warning emphasized short-term as opposed to long-term consequences, and among those subjects with a prosocial value orientation.

In summary, when the resource is in danger of depletion, we observe that prosocials are more cooperative than proselves (Brucks & Van Lange, 2007; Joireman et al., 2009; Kramer et al., 1986) but the former become as uncooperative as the latter when noise is present (Brucks & Van Lange, 2007). Regarding trust in others, high trusting individuals consume significantly less when the resource is in danger of depletion, comparing to "low trusters" (Brann & Foddy, 1987; Messick et al., 1983). Differences in cooperative behavior between collective and individualist cultures seem to emerge only under resource overuse (Liebrand, 1984; Samuelson et al., 1984) with individuals within a collective culture exhibiting more restraint in such conditions. Finally, the effectiveness of information on restraint when the resource is in danger of depletion depends both on timing (Joireman et al., 2009) and on specificity of the information given (Loomis et al., 1995).

Although this was contemplated in previous sections, it is worth to point out that when the resource is being overused we observe more cooperation when individuals share a collective identity (Brewer & Kramer, 1986; Kramer & Brewer, 1984). Additionally, resource overuse is associated with a stronger tendency for subjects to vote for a structural change by appointing a leader (Messick et al., 1983; Rutte & Wilke, 1984; Samuelson & Messick, 1986).

What happens after the tragedy of the commons?

To attempt to answer this question we will focus on the two studies that most closely resemble a post-crisis context. These studies led subjects to believe they were overusing the resource and then analyzed their harvest behavior in a 2nd Session.

The study described by Messick et al., (1983) also included a 2nd Session. In the 1st session, they manipulated subjects' perception of the resource use: underuse, optimal use or overuse; and homogeneity of harvesting behavior: low or high variance. They then allowed participants to vote for the election of a leader in a 2nd session and informed participants that they were the elected leader. Authors observed that, generally, the elected leaders in this 2nd session harvested much less than the 1st one and very close to the optimum level.

The pattern of results is displayed in Figure 1.5. Subjects previously in the *underuse condition*, took more than the optimal number of points in the first trials of session 2 and dramatically decreased their group harvests after, taking far less than the optimum. As to the subjects that previously experienced *optimal use condition*, they started at the same level as the underuse subjects, but gradually declined their harvests, behaving similarly in both sessions. In contrast, subjects who experienced the ***overused condition*** in session 1, seemed initially more cautious probably due to the previous overuse, but then greatly increased their harvests and, when the pool size was very low, reduced them in order to avoid resource extinction, which corresponds to a low risk strategy.

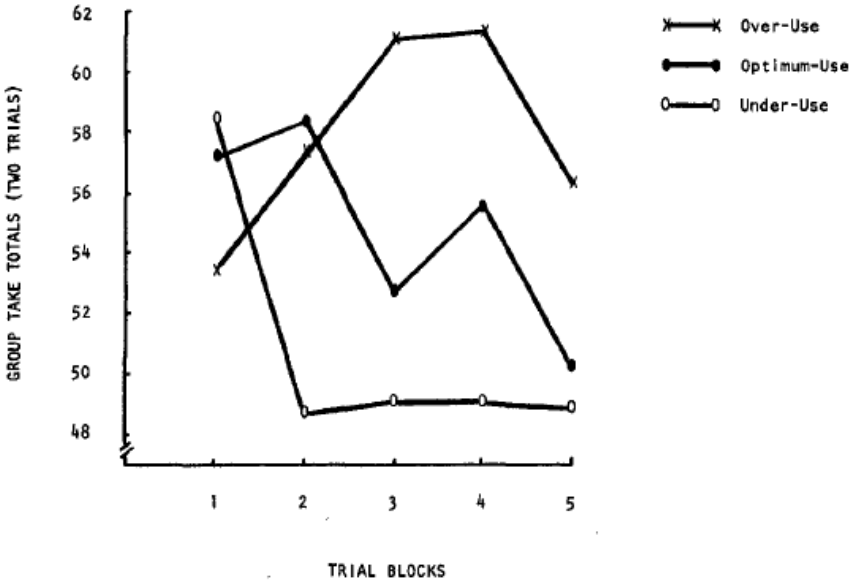

Figure 1.5 Mean group harvests per trial block, for each resource use condition. Adapted from "Individual Adaptations and Structural Change as Solutions to Social Dilemmas," by D. M. Messick and H. Wilke, M.B. Brewer, R. M. Kramer, P. E. Zemke, and L. Lui, 1983, *Journal of Personality and Social Psychology, 44*, p. 304. Copyright 1983 by the American Psychological Association, Inc.

Finally, "high trust" subjects (who expected other group members to reciprocate self-restraint) reliably took less than low trust subjects in the second session; and continued to take less even when others were overharvesting and the resource approached extinction. Although not evaluated in this study, the "level of trust" is probably related to subjects' social value orientation. "High trusters" should be more prosocial, since prosocial individuals tend to expect others to reciprocate cooperation (Bogaert et al., 2008) and continue to cooperate even when other group members do not reciprocate (Kramer et al., 1986).

Rutte & Wilke, (1984) used a similar design, manipulating resource status through feedback (underuse, optimal and overuse) in a 1st session and informing participants they were selected as leaders for a 2nd session. While in Messick et al 1983 study all participants faced similar resource conditions (replenishment rate) in the 2nd session, in Rutte & Wilke, 1984

study participants experienced the same resource conditions in both sessions. That is, subjects who experienced resource overuse in the 1st session (low regeneration rate), also experienced the same low regeneration rate in the 2nd session. Authors replicated the previous finding that leaders in the 2nd session harvested less than in the 1st session as a regular group member. Leaders coming from optimum use condition in Session 1, deal efficiently with the resource in session 2, guaranteeing optimal outcomes for the group. As shown in Table 1.2, leaders coming from overuse condition overuse the resource and leaders coming from underuse condition, underuse the resource.

Table 1.2

Leader harvests per group member summed up over ten trials.

Use conditions	Theoretically advisable	Actual	Difference
Over	14.56	21.66	7.1*
Optimum	45.45	46.15	0.7
Under	72.64	66.89	−6.0*

Adapted from "Social dilemmas and leadership," by C. G. Rutte and H. A. M. Wilke, 1984, *European Journal of Social Psychology, 14,* p. 114. Copyright 1984 by John Wiley & Sons, Ltd.

* $p < .05$

For example, the elected leader who experienced resource underuse in a 1st session continues to underuse the resource in a s 2nd session, despite having complete power over resource distribution. As authors suggest this may reflect leaders conforming to what they possibly perceive as a group norm. However, the fact that subjects experienced the same resource conditions (replenishment rate) in both sessions does not allow the comparison between the three conditions. Only using a similar design to Messick et al., (1983) with

participants facing similar conditions of replenishment rate in a 2nd session can we analyze the effect of resource use in a 1st session on the harvest behavior in a 2nd one.

In both of these studies, the fact that subjects took the role of leaders probably induced them to be more cooperative than as if they were a group member, because they were the single person responsible for the resource status and believed they were elected by other group members. It would be interesting to look into their behavior if they were selected at random to be the group leader in the 2nd Session. Moreover, manipulating whether or not they believed other members knew or not who the elected leader was.

Hence, what does happen after the tragedy of the commons? The studies that closely resemble the experimental design that allows answering this question are the ones from Messick et al., (1983) and Rutte & Wilke, (1984). However, participants who experienced "resource overuse" did not experienced a resource crisis in terms of very early resource depletion. Moreover, in their "post-crisis" context (here, post-resource overuse) in a 2nd session, participants were acting as leaders instead of individual group members.

So what do these studies tell us? That, after experiencing resource overuse, subjects who experience a normal regenerating pool will probably be more restrained initially and increase their harvests over time but reducing them when the resource is in danger of depletion. On the other hand, subjects that, after experiencing resource overuse, again experience a slowly regenerating pool, will probably tend to overharvest.

We also anticipate an effect of social value orientation after the resource crisis. Since prosocials continue to exhibit restraint even if others do not, we expect that, in a post-crisis context, prosocials cooperate more than proselves, regardless of the resource having a low or

high danger of depletion. Nevertheless, the magnitude of this difference will probably be increased when the resource is again in danger of depletion (High Danger).

FISH task: a commons dilemma simulation

The commons dilemma we will use is the FISH 5.0 program (Aranda, n.d.). The FISH is a Java-based application used in research to study commons dilemmas (Gifford & Gifford, 2000).The program uses ocean fishing as a metaphor, where fishes represent the resource. Fishes spawn periodically, symbolizing the regeneration of the resource. The FISH 5.0 not only has a modern and intuitive design, but also allows the manipulation of several parameters. Subjects can either play alone or with others and with human or computer fishers. The parameters we can manipulate are: the number of resource units (fish), participants (fishers), and trials (seasons), payoff values, the resource regeneration rate (spawning), harvesting greed by computer fishers, awareness of other harvesters' actions, among others.

Typically, the game goes as follows: several fishers play together, harvesting as many fish as they want in each round, knowing each fish has a given value. After the end of each round, fishes spawn and the next round starts with more fish. The regeneration rate feature of game manipulates the amount of fishes that will spawn. Fishers' harvesting behavior will determine how long the resource (fishes) will survive, because fishers' greediness may lead to resource depletion if they do not restrain themselves to allow fishes to spawn at a stable rate.

In the FISH simulation, participants can either play with real people or with pre-programmed fishers, the latter are also called bots. The usage of bots allows the experimenters to control and better standardize the behavior of the "other players". The bots' features that can be manipulated are the following: name, greed, trend, greed spread and predictability (see Appendix B).

When selecting the parameters for the FISH task we accounted for the findings of previous studies on the situational variables that influence cooperation in a commons. We will briefly explain our choices of group size, privacy of choices, information on strategies and resource status (environmental uncertainty and resource use). When building the task there were two salient goals: promote cooperative behavior but simultaneously resemble a real-life commons management.

In the FISH task, participants played in groups of 5 (with 4 bots). This choice of **group size** had two factors in mind. First, we wanted to promote deindividuation and diffusion of responsibility, two phenomena that occur in larger groups (Festinger et al., 1952; Latané & Darley, 1968). Most of our decisions concerning experimental design promoted cooperation, so why are we increasing group size knowing beforehand that it has a prejudicial effect on cooperative behavior? Real-world resource management problems involve large groups, with each member trying to maximize its own gain. Using the fishing industry as an example, there are several fishing companies fighting over stock and territory. Thus, the goal was to increase ecological validity. We actually wanted to increase group size even further but here is where the second reason emerges. We needed participants to believe they were playing online with human players and the more participants (bots) we included, the less realistic it would seem.

Regarding the **privacy of choices**, we let participants' choices be public but anonymous. Although there is some inconsistency regarding the effects of identifiability on cooperation in social dilemmas (Dawes, 1980; Williams et al., 1995) we believe this variability comes mainly from differences in the experimental design and that, in general, identifiability promotes cooperative behavior. In the FISH task, we set participants choices to be public. Although usually this is not the case in real life, we believe this was necessary for participants to believe they were playing with others online by seeing the table updating with information on "other players". However, in these uncertain contexts when choices are public, subjects

have the tendency for social conformity (e.g. Schroeder, Jensen, Reed, Sullivan, & Schwab, 1983). To avoid this, we set bot harvest behavior to be heterogeneous so there was no "harvest norm" for participants to follow. In the task, choices were also anonymous, which not only resembles real life situations but also eliminates the problem of gender identification. As mentioned earlier, there is an association between sex and cooperation moderated by the social context (Balliet, Li, Macfarlan, & Van Vugt, 2011) and, to avoid confounders, we opted to attribute participants a random code (e.g lb693)

Providing **information about strategies** yields positive results in resource management efficiency (Hine, 1990). We opted to conceal the optimal strategy (which corresponded to 10 fishes per player per round) because the optimal strategy is often unavailable in real life. However, to avoid early depletion of the resource we told participants that the goal was to get as many points as possible at the end of the game and this implied letting the game continue for as many rounds as possible.

Regarding **environmental uncertainty**, in the FISH task, there was full resource visibility to avoid the participants' tendency to overestimate the pool size (Budescu et al., 1990) and, consequently, overharvest and reduce efficiency levels (Budescu, Suleiman, et al., 1995; Gustafsson et al., 1999; Hine & Gifford, 1996). Uncertainty regarding the regeneration rate of the pool also produces significant declines in individual restraint and group efficiency (Hine & Gifford, 1996). In our task, the regeneration rate was not revealed and subjects were only informed that fishes might regenerate faster or slower in different stages due to external variables such as maritime currents, etc. This possibly promoted overharvesting but we used a visual cue – resource turning grey – as an indicator of resource overconsumption, to counteract this effect. Finally, we did not reveal the number of trials in order to avoid end of game effects (Bar-El & Tobol, 2013). Once subjects knew which was the final round, they would take as much fishes as possible and deplete the resource.

Finally, we manipulated **resource status** (in terms of overuse, optimal use and underuse) by changing the bots' greed, greed spread and regeneration rate parameters (for further details see Method and Supplementary Materials).

3. From brain to behavior: glucose and decision-making

Previously we offered the theoretic background on human cooperation and presented the commons dilemma paradigm used to study it. Now we move on to understanding how glucose may influence cooperation. Currently there are no studies on the connection between glucose and cooperation and past work focused mainly on the effect of glucose on other categories of decision-making. This chapter begins by describing how glucose is metabolized in the brain, how the brain operates under different glycemic levels and presenting some models that attempt brain energy usage. Subsequently we present the main findings on how glucose influences decision-making and, finally, reflect on how it may influence cooperative behavior.

Glucose in the brain

Glucose is an obligatory energy substrate for the brain (Bélanger, Allaman, & Magistretti, 2011). Although the brain consists approximately of 2% of the body, it consumes around 20% of glucose-derived energy, making it the main consumer of glucose (Mergenthaler et al., 2013). Only under specific and extreme conditions, such as fasting and uncontrolled diabetes, are the brain's energetic requirements sustained by other compounds (Magistretti & Allaman, 2015). Given glucose is the main fuel in the brain under normal conditions, it has become the focus of **neuroenergetics**, the field studying energy flow within the brain and the energy demands of neural function.

The brain cannot synthesize glucose, so it requires a virtually continuous supply of glucose from the circulation (Cryer, 2007). How does glucose reach the brain? How is it metabolized? Specialized centers in the brain sense central and peripheral glucose levels and regulate glucose metabolism through the vagal nerve as well as neuroendocrine signals (Mergenthaler et al., 2013). Once glucose reaches the bloodstream it has to cross the blood brain barrier before entering the brain. The blood brain barrier is a membrane that separates the

circulating blood from the brain, allowing the passive diffusion of some molecules but requiring selective transport for others, such as glucose that passes through a glucose transporter (GLUT1). Once it reaches the brain, how does glucose support brain activity? A model of brain energy use suggests that a considerably larger amount of energy is spent in the grey matter compared with the white matter (Harris, Jolivet, & Attwell, 2012). Of constituents of grey matter, neurons and astrocytes are the main consumers of glucose in the brain (Mergenthaler et al., 2013).

Neurons are the basic cell unit of the nervous system that receive, process, and transmit information through electrical and chemical signals; and communicate with other neurons via specialized connections called synapses, through neurotransmitters. Surrounding neurons, there are glial cells, which include astrocytes that are, in turn, essential for the structural and metabolic support of neurons, among other functions.

Neurons and astrocytes process glucose differently and exhibit key interactions to produce glucose-derived energy in the form of ATP, which is considered the "molecular unit of currency" of cells from most organisms. Therefore, which processes consume ATP and how is this energy delivered? It appears that neurons consume 75-80% of the energy produced and consume most of it at the synapse (Harris et al., 2012)

There has been some controversy regarding the major fuel for activated neurons and the models for neuron–astrocyte interactions (Mergenthaler et al., 2013). The debate circles around two mechanisms: Astrocyte-Neuron Lactate Shuttle and Neuron-to-Astrocyte Lactate Shuttle. Some members of the neurochemistry community defend that the mechanism that couples synaptic activity to local energy delivery is the *Astrocyte-Neuron Lactate Shuttle* (ANLS). The ANLS mechanism suggests that astrocytes predominantly process glucose through *aerobic glycolysis* to produce pyruvate and lactate; and neurons predominantly use *oxidation* of these substrates – pyruvate and lactate – to produce ATP (Magistretti & Allaman,

2015). The ANLS suggests that the uptake of synaptically released glutamate into astrocytes as a consequence of neural activity represents a key signal to import glucose into astrocytes and produce lactate as an energy substrate (see Appendix C). This becomes a highly efficient energy delivery mechanism since glutamate is the predominant signal of increased synaptic activity and hence increased local energy demands. Others suggested a different mechanism of glucose metabolism (e.g. DiNuzzo, Mangia, Maraviglia, & Giove, 2010; Patel et al., 2014). This mechanism is the *Neuron-to-Astrocyte Lactate Shuttle* (NALS), which predicts glucose is predominantly taken up into neurons due to their high energy demand and lactate is posited to be generated by neurons and taken up by astrocytes (Mergenthaler et al., 2013). However, it is the ANLS model that better integrates data from different methods such as positon emission tomography (PET), functional magnetic resonance imaging (fMRI) and magnetic resonance spectroscopy (MRS) (Magistretti & Allaman, 2015).

Another mechanism of neuron-glia metabolic coupling involves the mobilization of glycogen, which is the main the storage form of glucose in the body. Specific neurotransmitters and neuromodulators[6] promote glycogenolysis in astrocytes, with the main ones being vasoactive intestinal peptide (VIP) and noradrenaline (NA) (Magistretti & Allaman, 2015). The brain is able to store glycogen and uses this compound when plasma glucose levels are low (Rooijackers et al., 2016).

Therefore, there are two main mechanisms for coupling neuronal activity to energy delivery by astrocytes: aerobic glycolysis triggered mainly by glutamate (from ANLS perspective); and glycogenolysis, stimulated by VIP/NA. Both processes lead to the release of lactate from astrocytes for use by neurons with the first one predominating under normal glycemic conditions. These observations shifted neuroenergetics from a "neurocentric" view

[6] Neuromodulators are a subset of neurotransmitters that, once released by neurons, diffuse through large areas of the nervous system, regulating the activity of multiple neurons.

into an integrated perspective on the metabolic complementary between neurons and astrocytes (Bélanger et al., 2011).

A remarkable feature of brain energy metabolism is the tight coupling between energy demand and supply, reflected by the delivery of glucose and oxygen from the vasculature (Bélanger et al., 2011). Task-dependent increases in cerebral activity are always accompanied by changes in regional cerebral blood flow (rCBF) and cerebral glucose metabolism (CMRglu), processes denoted as neurovascular and neurometabolic coupling, respectively.

The previous section serves to illustrate that there is still a lot to learn about glucose metabolism in the brain, highlighting the cellular mechanisms and metabolic interactions between neurons and astrocytes under normal and abnormal blood glucose levels. Now that we have a basic grasp of what is known about the processes that fuel neuronal activity, let us focus on how are these neural processes affected by varying glucose levels.

According to the National Institute of Clinical Excellence, the normal glycemia levels (normoglycemia) are between 72 and 108 mg/dL when fasting and up to 140mg/dL 2h after eating. Hyperglycemia occurs when there is an excessive amount of glucose in the blood plasma, whereas hypoglycemia occurs when blood glucose drops below normal levels and is defined as any blood glucose measurement that falls below 70mg/dL (American Diabetes Association, 2013). So, what happens as our blood glucose levels get lower? As the hypoglycemia progresses, we display decreased cognition (from difficulty in concentrating to overt confusion), aberrant behavior, seizures, coma and, with profound and prolonged hypoglycemia, neuronal death (Cryer, 2007).

There is evidence from type 1 diabetic patients demonstrating that the brain operates differently under hypoglycemia (Rooijackers et al., 2016). At a neurochemical level, no differences were observed in cerebral glucose metabolism (CMRgl) between hypoglycemia

and normoglycemia neither in healthy controls nor in patients with type 1 diabetes. However, under hypoglycemia, there is evidence of greater use of brain glycogen (both in humans and in rodents) and reduced brain glutamate levels in healthy controls. Data from functional and metabolic neuroimaging techniques suggest that, globally, cerebral glucose metabolism (CMRgl) is unchanged during moderate hypoglycemia[7] (Rooijackers et al., 2016). However, on the regional level, moderate hypoglycemia causes redistribution of CBF to various brain areas involved in the detection of hypoglycemia where enhanced neuronal activation stimulates glucose uptake and metabolism. Moreover, the highest increments in regional CBF during hypoglycemia occur in the frontal and parietal lobes (Tallroth, Ryding, & Agardh, 1992). Parietal lobes are responsible for integrating multisensory information, among other functions; and frontal lobes are responsible for executive functions such as attention, inhibition, working memory, planning, reasoning and decision-making. As such, hypoglycemia is expected to impair these cognitive functions, and there is evidence to support it (see Feldman & Barshi, 2007; Orquin & Kurzban, 2016 for reviews)

As described, the brain operates differently under hypoglycemic conditions. However, hypoglycemia in healthy individuals is very uncommon (Desimone & Weinstock, 2000) and this is due to a coordinated system that suppresses insulin[8] production once glucose levels reach low values (Rooijackers et al., 2016). In the present work, we are interested in the altered cognition resulting from lower than average blood glucose levels, still under normoglycemia, since relatively subtle changes in glucose can influence on thought and behavior (Gailliot & Baumeister, 2007). As we shall discuss later, even before entering a hypoglycemic state, our cognitive processing is already impaired. As depicted in Figure 1.6, our glycemic levels vary throughout the day but only fall into hypoglycemia if we go several hours without eating.

[7] Between 40-50 mg/dL (Davis & Lastra-Gonzalez, 2008).
[8] Insulin is a hormone responsible for blood glucose regulation. High concentrations of insulin in the bloodstream decrease blood glucose levels.

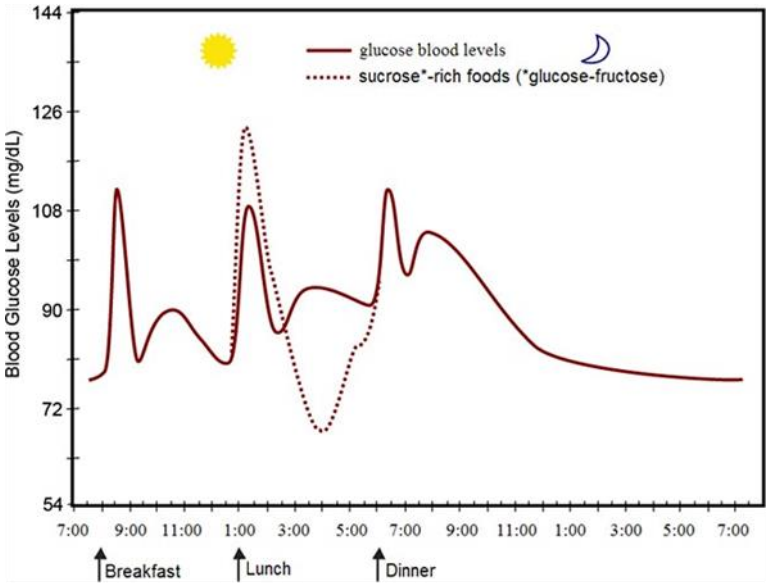

Figure 1.6 Fluctuation of blood sugar (red) in humans during the course of a day with three meals. Adaptated from "Pancreas islets in metabolic signaling - focus on the β-cell," by J. Suckale and M. Solimena, 2008, *Frontiers in Bioscience, 13,* p. 3. Original from "Acute effects on insulin sensitivity and diurnal metabolic profiles of a high-sucrose compared with a high-starch diet," by M. E. Daly, C. Vale, M. Walker, A. Littlefield, K. G. MM Alberti and J. C. Mathers, 1998, *American Journal of Clinical Nutrition, 67,* p.1190. Copyright 1998 by American Society of Clinical nutrition.

How does this glycemic variability affect cognitive processes? Since human cognition operates within biological constraints, it is not surprising that hypoglycemia causes performance decrements in cognitive tasks (see Feldman & Barshi, 2007 for a review). Therefore, it is expected that lower glucose levels (major fuel of the brain) are associated with decreased cognitive resources. In other words, depriving the brain of its major energetic substrate results in increased cost for brain function. In chapter 1, we explained that humans have bounded rationality and that we use mental shortcuts (heuristics) to mitigate the cognitive

costs of complex decision-making. Now we may ask ourselves: what exactly is being spent? Is it glucose? Three models give different answers to this question.

The **cost-benefit models** of cognitive cost assume individuals attempt to optimally trade costs (leisure, opportunity cost, cognitive demand) for benefits (reward, leisure). However, these models totally decouple cognition from its limited biological substrate - the brain. Next, the **limited resource models** linked cognitive cost to the utilization of a limited resource, purportedly blood glucose (Gailliot et al., 2007). These models posited glucose as the physiological substrate of self-control "resource" (Hagger, Wood, Stiff, & Chatzisarantis, 2010). Although these models establish a bridge between a biological substrate and cognitive cost, they have several limitations. The most striking is that the reported decreases in blood sugar resulting from cognitive demanding task are too small to disrupt task performance. A reanalysis of the self-control literature failed to find the effect predicted by the glucose model of self-control (Kurzban, 2010) and the corollaries of this theory were not confirmed in a recent meta-analysis (Dang, 2016).

Recently, a model of cognitive cost was suggested based on the novel idea that the brain senses and plans for longer-term allocation of metabolic resources by intentionally conserving brain activity. This **optimal control model** of energy use in the brain **s**uggests that an individual's decision of paying cognitive costs is strategic: he/she will only commit limited resources if the payoff is worth it (Christie & Schrater, 2015)**.** Hence, what may appear to be aversion to cognitive effort or cognitive laziness may in fact be strategic resource allocation. This model uses astrocytic glycogen as a plausible basis for limited energetic reserves, suggesting glycogen acts as an energy buffer that can temporarily support high neural activity beyond the rate supported by blood glucose supply. Authors suggest the existence of a control system that reallocates energetic stores of glycogen to anticipate and meet the demands of recurrent neural activity at longer timescales. In their paper, Christie and Schrater define:

- System state as the resources available in different components of the brain (energy residing in astrocytes and neurons)
- System dynamics as the energy flow between capillaries, astrocytes, and neurons within an area.
- Control of the system as a mechanism that increases and decreases energy usage rate by changing the concentration of some excitatory neuromodulator. Botvinick & Braver, (2015) suggested dopamine as a candidate control signal.
- Objective function as the combination of cognitive costs and rewards per time unit

In sum, this optimal control model views the allocation of metabolic resources as a control problem with the limitation given by the dynamics of glycogen storage and use. It proposes the existence of a control system that optimizes energy consumption, even though no system is specified and future studies are required to verify or disprove this model.

The models presented above serve to illustrate that the biological processes linking glucose levels to cognitive cost remains an open question for future research. While this section focused on the molecular and cellular processes involved in glucose metabolism under normal and abnormal conditions, the following segment centers around one of the cognitive processes affected by lower blood glucose – decision-making.

Glucose and decision-making

Glucose levels influence several dimensions of human cognition (Orquin & Kurzban, 2016). The general idea is that glucose deprivation worsens cognitive performance whereas glucose enrichment improves it. For instance, glucose deprived participants have poorer performance on mental calculation and inhibition tasks (McElroy et al., 2014). On the other

hand, glucose enriched subjects improve their facial emotion recognition, verbal working memory, spatial abilities, inhibition and processing speed. However, the idea that ingesting sugar will inevitably improve cognitive function is too simplistic (Gibson, 2007) and experimental evidence should be taken carefully.

Evolutionary studies suggest an association between high cognitive functions in humans and significant expansion of our neocortex coupled with an increase in glucose utilization and the expression of energy metabolism genes (Magistretti & Allaman, 2015). That is, high cognitive functions are associated with higher energy expenditure through glucose metabolism, which possibly renders these functions the first to resent drops in blood glucose. Indeed, it is predicted that the degradation of cognitive functions as a result of declines in blood sugar will be stronger in high cognitive functions (Christie & Schrater, 2015), such as decision-making. This is in accordance with evidence that higher functions such as working memory, attention, and executive control are more sensitive to hypoglycemia than low level functions as auditory acuity and basic motor functions (Feldman & Barshi, 2007).

The studies on glucose and decision-making broadly suggests that lower glucose levels are associated with poorer decision-making and higher glucose levels with better decisions (e.g. Bos, Dijksterhuis, & van Baaren, 2012; Dickinson, McElroy, & Stroh, 2014; McMahon & Scheel, 2010). Literature on glucose and decision-making focused mainly on four topics: willingness to pay, willingness to work, future discounting and decision style.

It seems low blood glucose increases the willingness to spend money on food but lowers the willingness to spend money on anything not food related; and also increases the willingness to work on food related tasks but decreases the willingness to work on any other task (Orquin & Kurzban, 2016). Moreover, glucose deprived subjects seem to increase their **risk tolerance**; increase their **future discounting** by placing greater value on current rewards than future ones;

and adopt a more intuitive rather than deliberative **decision style**. For the purposes of this project, I will focus only on these last three findings[9].

a. Risk tolerance

Decision under risk can be seen as a choice between options (A, B, C) that yield outcomes (Xa, Xb, Xc) with a given probability (pa, pb, pc) (Kahneman & Tversky, 1979). Human behavior under risk is somewhat surprising from a purely economic perspective. We sometimes exhibit *risk-aversion*, preferring a sure outcome over a gamble with higher or equal expected value; or *risk-seeking*, rejecting a sure thing in favor of a gamble of lower or equal expected value (Kahneman & Tversky, 1984). Several factors influence human risk attitude and glucose levels are one of them. Only two studies focused on this topic and both suggest low levels of blood glucose lead to riskier choices (Orquin & Kurzban, 2016).

The effect of glucose on human risk-attitude in financial decisions was tested in a risk preference task where each trial consisted in a choice between two alternatives, one riskier than the other (Symmonds, Emmanuel, Drew, Batterham, & Dolan, 2010). Authors looked into acyl-ghrelin levels as an indicator of current metabolic state. Acyl-ghrelin, also called the "hunger hormone", is highly sensitive to short-term changes in metabolic state and higher levels of this hormone correlate with subjective indices of hunger. Results indicate delayed effects of the meal (1h after) on risk attitude correlate with changes in acyl-ghrelin. Individuals became more risk-averse while satiated, reflected by a greater post-prandial fall in acyl-ghrelin (i.e. larger signal of nutrient intake). A smaller change in acyl-ghrelin levels indicating a lower than anticipated impact of the meal, correlated with greater risk seeking. These results are in accordance with prospect theory, which postulates that changes in wealth below a reference point induce risk-seeking behavior and earnings above a reference point promote risk aversion.

[9] The experimental paradigm does not involve costs or work. Therefore, studies on willingness to pay and work are not informative on the effects of blood glucose on cooperative decision-making in our experimental task.

Later, another study tested participants in a risk preference task under satiated and deprived states where they had to choose between two rewards (Levy, Thavikulwat, & Glimcher, 2013). This task used money, food and water as rewards. Results indicate that subjects became overall more risk tolerant as they become overall hungrier and thirstier for all three reward types: money, food and water. When satiated, subjects showed very diverse risk attitudes, from highly risk-averse to weakly risk tolerant. When deprived, these risk attitudes converged towards a similar level of weak risk aversion, for all reward types. In summary, risk attitude seems to be state dependent and deprivation reduces the variance of human risk attitudes.

Taken together, both studies suggest decision makers with low levels of blood glucose tend to make riskier choices when the outcome is either food or money (Orquin & Kurzban, 2016). This is consistent with optimal foraging theory, which core principle of the budget rule proposes that animals under negative energy budgets will shift from risk averse to risk seeking. Nevertheless, one limitation from the previous studies is they do not provide pure measures of risk. Choosing the riskier choice may not reflect a more risk seeking attitude but instead the greater value of the riskier reward. Although the second study has the advantage of explicitly stating the reward probabilities, the claim that we are measuring only risk behavior is still inaccurate.

b. Future discounting

We discount the future when we value present goods over future goods and prefer a smaller and sooner reward to a larger but later reward (Wang & Dvorak, 2010). Several studies focused on the effect of glucose levels (through a hunger manipulation) on future discounting for food and non-food rewards. Since were interested in the latter, we will give it special attention.

Before getting into the effect of glucose on future discounting for food, we should recognize that we discount food even while satiated, that is, not glucose deprived. (Rasmussen, Lawyer, & Reilly, 2010) asked subjects to choose between different amounts of food at different delays or with different probabilities. The task consisted in questions such as: *Would you rather eat 10 bites of your favorite food in 1h, or 2 bites in 5h?*; or *Would you rather eat 5 bites of food that is certain or 10 bites of food with a 25% chance?* Results indicate the value of food decreased with time delay or chances against receiving the food.

Regarding the role of glucose on food-related future discounting, we discount food both when glucose enriched and glucose-deprived but to a larger extent when glucose-deprived (Hoefling & Strack, 2010; Kirk & Logue, 1997). Some other variables are associated with an increased future discounting for food, such as dieting (Logue & King, 1991) and higher body fat percentage (Rasmussen et al., 2010). Additionally, there is evidence of a gender effect, where women tend to make more impulsive and risk-averse choices for food, having higher future discounting rates than men for food items.

Similarly, to future discounting for food, we also discount money. That is, we often prefer receiving less money sooner than a larger amount of money later. This phenomenon happens even when we are satiated, that is, under normal glucose levels. Similar to their experiment on future discounting for food, Rasmussen, Lawyer, & Reilly, (2010) tested subjects for money discounting. Participants had to choose between different amounts of money available after different delays: *would you rather have $10 in 30 days or $2 at the end of the session?*; or with different probabilities: *would you rather have $5 for sure at the end of the session or $10 with a 25% chance?*. Results indicate the value of money decreased with time delay or chances against receiving the money.

Interestingly enough, we need not to manipulate subjects' glucose levels to elicit differences in money discounting. It seems the sheer presence of certain food stimuli (visual or

olfactory) is sufficient to increase money discounting rate (Li, 2008). In a first experiment, subjects were randomly assigned to an appetitive condition (dessert pictures), nonappetitive condition (neutral pictures) and control condition (no picture). Then they had a temporal orientation task with choice items such as *would you rather have $10 tomorrow vs $12 in 25 days* and later a vice vs virtue task choosing between alternatives such as *would you rather hire an attractive vs a competent job candidate*. Experiment 2 used the scent of food (cookies) to manipulate the appetitive state, followed by two tasks: 1) happiness ratings of monetary gains at different points of time; 2) and hypothetical purchase decisions. Results from both experiments indicate: subjects faced with appetitive stimuli were more present oriented and preferred smaller-sooner rather than larger-later monetary gains; preferred vice options to virtue options; were less happy with distant monetary gains; and were more likely to buy unplanned products under a very tight budget.

Having established how we typically discount money, the following studies analyze how glucose modulates money discounting. Not surprisingly, glucose-deprived subjects discount money further than glucose-enriched ones. Authors manipulated subjects' blood glucose levels by instructing participants not to eat before the experiment and have them drink either a sugary drink – experimental condition – or a drink with artificial sweetener – control condition (Wang & Dvorak, 2010). They then completed the final future-discounting task, which consisted in questions such as *Would you prefer $120 tomorrow or $450 in 31 days?*. Results indicate subjects with higher blood glucose levels increased the value placed on future rewards (less future discounting); and subjects with lower blood glucose increased the value placed on current rewards (more future discounting).

A recent study produced some unexpected results, although they generally support previous findings. Kuhn, Kuhn, & Villeval, (2014) asked participants to choose between receiving smaller tokens sooner or a higher amount later, with payment dates varying in five

weeks intervals - 0, 5, 10, 15, 20, 25, 30 weeks. To manipulate glucose levels, there were four conditions: 1) sugar drink; 2) placebo drink (sugar flavored only); 3) baseline (no drink); 4) depletion (no drink and depleting task[10]). Unexpectedly, the depletion group reduced future discounting and authors suggested the 'attention/focusing' effect of engaging in the depleting task primed subjects to think more carefully about their subsequent economic decisions. Drinking either the placebo beverage or the sugared beverage, reduced future discounting, in comparison to baseline, although the magnitude of the effect was significantly greater for the sugar group than the placebo. The fact that the placebo group also reduced future discounting in comparison to the baseline condition was somewhat surprising. However, recent studies showed that rinsing one's mouth with a sugary drink, even without swallowing, boosts self-control in similar ways to ingesting sugar – "rinsing effect" (see Dang, 2016 for a meta-analysis; Molden et al., 2012; Sanders, Shirk, Burgin, & Martin, 2012). Detecting carbohydrates in the mouth, even without ingesting them, may signal the possibility of reward and motivate physical effort. Thus, this could explain the increase in self-control in the placebo condition (vs baseline) observed by Kuhn et al., (2014), given their placebo drink contained a small amount of sugar.

Taken together, the analysis of future discounting revealed a significant, negative main effect of blood glucose levels, with no significant differences between the food- and nonfood-related tasks (Orquin & Kurzban, 2016). However, results suggest a moderator effect with low blood glucose increasing the future discount rate for food and to a lesser extent the discount rate for nonfood. This phenomenon of discounting hypothetical primary rewards (like food)

[10] The depletion task used was the Stroop task, a self-control task believed to reduce blood glucose levels (e.g. Gailliot et al., 2007), although a recent meta-analysis indicates it does not (see Dang, 2016)

more steeply than secondary rewards (such as money) is referred as the domain effect (Rasmussen et al., 2010).

c. Decision style

This section focuses solely on non-food domain studies regarding the effects of glucose on decision style. Here, decision style is characterized either as more intuitive/unconscious or as more deliberative/conscious. This relates to the dual process theory of cognition, that, recapitulating, differentiates two types of cognitive processing: 1) one that is fast, automatic, effortless, associative and difficult to control - intuition system; and another that is much slower, serial, effortful, rule-governed and deliberately controlled - reasoning system (Kahneman, 2003).

There is evidence suggesting low glucose levels influence decision-making style, even in experts. This research examined if judges were able to decide in a rational and deliberative manner or if there were also psychological factors influencing judicial rulings (Danziger, Levav, & Avnaim-Pesso, 2011). Judges had two daily food breaks – a morning snack and lunch, breaking the day into three distinct "decision sessions." These breaks possibly replenished judges' mental resources either through rest, improving mood or by increasing glucose levels. The judges' decisions on prisoner's requests were classified into two categories: "accept request" and "reject request", with the latter being the default outcome. Authors found the likelihood of a favorable ruling – "accept request"[11] – was greater at the beginning of the workday or after a food break, as displayed in Figure 1.7.

[11] The majority of the decisions consisted of parole requests; the remainder consisted requests to change the terms of their parole (e.g., remove a tracking device) or requests to change the terms of their incarceration (e.g., prison relocation).

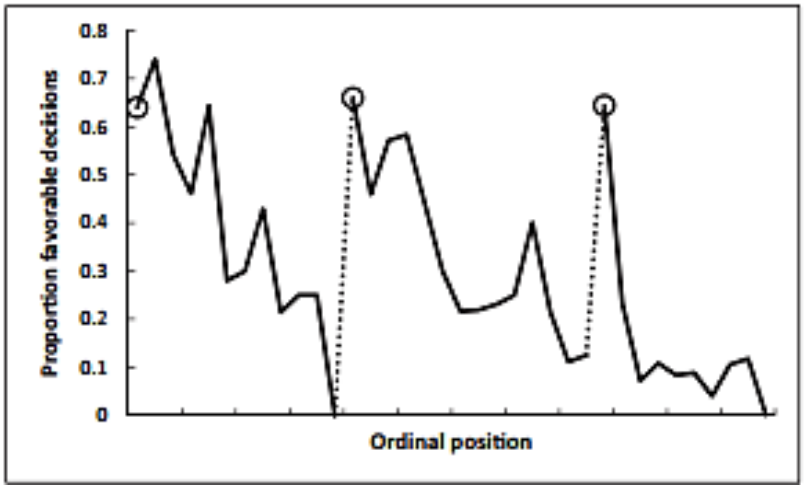

Figure 1.7 Proportion of rulings in favor of the prisoners by ordinal position. Adapted from "Extraneous factors in judicial decisions," by S. Danziger, J. Levav and L. Avnaim-Pesso, 2011, *Proceedings of the National Academy of Sciences, 108,* p. 6890.

Circled points indicate the first decision in each sessions; tick marks on x axis denote every third case; dotted line denotes food break

*p < 0.1, **p < 0.05, ***p < 0.01

The data suggests that when judges make repeated rulings, they increased their tendency to accept the default outcome: reject the prisoner's request. However, taking a break to eat a meal, overcomes this tendency. We cannot say if only resting or eating would produce the same effect on mental resources. Nevertheless, these results do indicate that extraneous variables, possibly subjects' glucose levels, can influence judicial decisions. The following studies are less vulnerable to confounding variables such as mood and rest and clarify that glucose does indeed influence decision-making style.

Higher glucose levels seem to improve learning of probabilities, favoring a deliberative type of processing (McMahon & Scheel, 2010). In this study, participants drank either regular beer or diet sugar-free beer before working on a probability-learning task where they tried to predict which of two events would occur on each trial. Results indicate that ingesting sugar

before working on a probability learning task promoted probability matching. There were no differences in reaction times between groups: even though glucose enhances overall processing speed, it also promotes more deliberation, which is more time consuming.

In line with the previous study, Dickinson et al., (2014) found higher glucose levels are also associated with improved weighing of outcome probabilities. Participants fasted three hours before the experimental session and drank either sugary lemonade (glucose condition) or sweetened lemonade with no sugar (placebo condition). Fifteen minutes later, they completed a Bayes switching task, where they could earn $10 or $0 per trial. In each trial, they had to decide between two options by weighing outcome probabilities. This dual option task allowed separating Bayesian decision makers (using the reasoning system) from those who follow a more simple reinforcement heuristic (drawing from the intuition system). Regarding **reaction times**: participants in the glucose condition took significantly longer to respond initially, indicating they were more deliberative; but reduced their reaction times overall when compared to the placebo group, suggesting a significant glucose impact on learning. As to **choice quality**, the probability of making a Bayesian choice (higher quality) rather than a reinforcement choice (low quality), was higher in the glucose condition. These results indicate a beneficial glucose effect on overall quality of choice in the Bayesian task.

Adding to the idea that higher glucose levels promote a deliberative type of processing (system 2), glucose-enriched subjects actually improve the quality of their deliberative choices. (Bos et al., 2012). Participants were asked not to eat or drink three hours prior to coming into the lab. Half the participants were given sugary 7-Up and the other half sugar free 7-Up and then saw a neutral video so glucose could have an effect on the brain. Next, participants read information about 8 hypothetical items that varied in degree of quality. Each item was described by several positive and negative attributes. Then, they were randomly assigned to a conscious thought condition (requires mental effort, eliciting the reasoning system) – “think

about the information carefully for 4min so you can later make a decision"; or unconscious thought condition (effortless, promoting intuition system to operate) - saw an unrelated movie clip. After, participants gave their attitude toward each of the 4 options from 1 (very negative) to 20 (very positive). Conscious deliberation improved subjects' ratings, measured by greater ability to distinguish good from bad options, when blood glucose levels were increased. Surprisingly, performance after unconscious processing actually declined when blood glucose was increased. Authors concluded that conscious deliberation yields the best results when blood glucose levels are elevated whereas unconscious thought leads to better results when glucose levels are reduced.

We already established high glucose levels promote the reasoning system to operate. Likewise, we observe that under lower glucose levels we turn to the intuition system instead (Masicampo & Baumeister, 2008). Using a similar manipulation of glucose levels authors focused on the attraction effect – an indicator of intuitive processing. Subjects ingested a drink: sugary lemonade (glucose group) or lemonade with sweetener and no sugar (placebo group). Participants watched a video and were instructed to form an impression on the person there depicted. Half of the participants were asked to ignore some visual cues, which requires some mental effort and exerting cognitive load (depletion group); and the other half had no further instructions (no depletion condition). Finally, they completed a consumer decision task. Authors were interested in the effects of glucose on the attraction effect, where a difficult choice between two options is swayed by the presence of a seemingly irrelevant ''decoy'' option. The attraction effect is an indicator of intuition system processing since there is no logical reason for the attraction to occur. This effect was strongest in the depleted-placebo group and they exhibited a significantly larger attraction effect than participants in the no-depletion conditions. This supports the idea that depleting cognitive resources increases heuristic and intuitive processing. Within the depletion condition, the glucose group exhibited

a smaller attraction effect than the placebo group. This finding also indicates that glucose intake eliminates the effect of resource depletion on decision-making and restores deliberative choice.

The analysis of these studies yielded a significant positive effect of blood glucose levels on decision style, with low blood glucose increasing the propensity to make intuitive decisions rather than deliberate ones, on non-food related tasks. (Orquin & Kurzban, 2016).

One limitation of the abovementioned studies on decision style, future discounting and risk tolerance is most of them do not present a measure of blood glucose levels. To make sure the glucose manipulation results in significant differences between groups, in our study we measured subjects' blood glucose levels directly.

Glucose and cooperation

Currently there are no studies focusing on the effects of blood glucose on cooperative behavior. However, the research presented above on the effects of glucose on decision-making might be informative regarding its effects on human cooperation. Let us consider the three main pieces of evidence gathered and reflect about how these might translate into our experimental paradigm.

Firstly, the qualitative analysis on glucose and risk suggests that higher glucose levels are associated with more risk aversion and lower glucose levels with greater risk seeking. Hence, we expect that in the FISH task, glucose enriched subjects opt for a "safer strategy" in comparison to glucose-deprived participants. The task has some degree of uncertainty, namely regarding how other players will behave, despite their choices being public, and concerning the regeneration rate of the pool. We expect that risk averse subjects (here, our glucose group) will be more cooperative, since this is the strategy involving less risk. In other words, we expect

risk seekers (here, our placebo group) will be more competitive, since this is a higher risk strategy.

Secondly, the literature on future discounting indicates that glucose enriched participants discount the future to a lesser extent than glucose deprived subjects. That is, subjects with high glucose tend to value more the larger and later rewards than subjects with low glucose. This notion is key to successful resource management in the FISH task. Consequently, we expect subjects with higher blood glucose to be more cooperative and successful in the experimental task.

Thirdly, the few studies conducted on decision style demonstrate that glucose deprivation is associated with an intuitive type of processing while glucose enrichment promotes a deliberative processing style. In one-shot games, the rational choice is to defect whereas in repeated games, such as the FISH task, the best strategy is to cooperate. The Social Heuristics Hypothesis suggests that, in repeated games, both intuitive and deliberative processing styles promote cooperation since: 1) it is intuitive to cooperate; 2) deliberation yields strategic cooperation, as confirmed in a recent meta-analysis (Rand, 2016). Thus the SHH predicts no differences on cooperative output despite different processing styles. However, we expect that a deliberative processing style will result in improved resource management.

Finally, regarding post-crisis behavior we expect that the glucose-enriched group is again more cooperative. Following a resource overuse period (crisis), it was demonstrated by a single study that if subjects act as leaders they were more cooperative in the initial trials, reducing their harvests (Messick et al., 1983). They subsequently increased their harvests over time but again reduced them when the pool size was low. This is a low risk strategy and, for this reason, we expect it from the glucose-enriched group. We anticipate this at least for the Low Danger condition of Stage 3. For the High Danger condition, the glucose group can either

be more cooperative than the placebo again revealing a safer strategy; or as competitive as the placebo once they realize the resource is again in danger of depletion.

Moreover, it is expected that subjects' social value orientation will influence cooperative behavior on the FISH task, although no interactions with the glucose manipulation are anticipated. We expect to replicate previous results, with prosocials being more cooperative than proselves across all conditions (e.g. Balliet et al., 2009; Budescu, Au, & Chen, 1997; Joireman, Posey, Truelove, & Parks, 2009; Kramer, McClintock, & Messick, 1986; Liebrand, 1984; Liebrand & van Run, 1985; Loomis, Samuelson, & Sell, 1995; Parks, 1994; Roch & Samuelson, 1997).

II. Method

Design

The experiment consisted in a 2 Glucose (glucose vs. placebo) x 2 Danger (High vs. Low) factorial design, between subjects.

Sample

Subjects were male and female volunteers, between the ages of 18 to 60 years old. The exclusion criteria were participants diagnosed with diabetes or hypoglycemia; and hemophilia or blood coagulation problems. Subjects were recruited through non-probability "snowball" sampling method, where each one was encouraged to ask their friends or family if they would be interested in participating.

Sample size was defined based on the standard effect size in psychology (0.5) using GPower (version 3.1) software. The required sample size to achieve a power of 0.8 with an α = 0.05 would be 64 participants per experimental group, amounting to a total N of 256 in our 2 x 2 design. We were only able to analyze data from 47 participants (around 12 participants per experimental group).

Ethical approval of this project was granted by Comité de Ética e Deontologia da Faculdade de Psicologia e Instituto de Educação da Universidade de Lisboa.

Procedure

Participants were tested either individually or in groups (maximum of 3) in a quiet room where the experimenter was also present during the entire experimental session. Upon arrival, subjects read the informed consent sheet (Appendix D). Immediately after, the experimenter

asked if they had any further questions and made sure he/she understood how the experimental session would proceed.

Participants sat before a computer screen, opened a qualtrics link and a welcome message appeared. Then, participants were asked to drink a beverage that was placed in front of them. Half of the participants drank 350 ml of sugary apple juice (brand Pingo Doce) - ~37g of sugar - and the other half drank 350ml of sweetened apple juice (brand Continente), a sweetened but sugar-free drink - 0g of sugar (similar procedure used in Masicampo & Baumeister, 2008; McElroy, Dickinson, & Stroh, 2014; McMahon & Scheel, 2010). Participants were unaware of the glucose manipulation.

After drinking the whole cup, subjects answered a liking index (2min) for the drink they just had to assure there were no differences in drink likability across groups. Both drinks were previously pretested with N=15 and there were no significant differences in drink likability. In the pretest, subjects were instructed to rate the quality of two competing juice brands, coded as "A" and "B". Drink order was counterbalanced across subjects.

Afterwards, they completed the Social Value Orientation task, which took approximately 5min (Appendix E). Following the SVO task, subjects filled some demographic information regarding their age, gender, nationality and education level. We also asked them how long it had been since their last meal/snack and about their sleeping habits. Finally, subjects saw the video tutorial explaining how to play the FISH program (3min) - youtu.be/mDHMYB0dHgk. The video tutorial was recorded using Active Presenter (version 6.0) and the sound quality was improved through Audacity (version 2.1.2). In the tutorial, participants were presented with the display they would see during the task (Appendix F).

The time spent answering the liking index, SVO task, demographic information and watching the tutorial amounted to the 10-12min necessary for necessary for glucose in a liquid to have an effect on the brain (Masicampo & Baumeister, 2008). At this point, we measured

the participants' blood sugar levels using a *One Touch Select Plus* glucometer (2min). Since we tested several subjects, each participant used a different lancet (puncture needle), so that everyone used completely sterilized material. The procedure went as follows: a lancing device was used to puncture the subjects' fingertip (ring or little finger) of their non-dominant hand, which was previously sterilized using an alcohol wipe. The participant gently massaged his/her fingertip until a round drop of blood formed. The blood drop was absorbed by a paper strip, which was inserted into the glucometer, providing a reading of glucose levels seconds later. The used lancet was thrown away. To assure this procedure went with the necessary precautions and minimal discomfort, the experimenter received training to use this device by a healthcare practitioner.

Later, subjects started the FISH task, which took around 10min. Participants were told they would play with other people who were currently online. Actually, they were playing with pre-programmed fishers – bots. The reason for using bots instead of real players was for us to be able to control and better standardize the behavior of the "other players". Subjects began by playing 3 practice rounds to get acquainted with the task display and response buttons. Then, the experimental trials began, and these were divided into 3 stages. Subjects were told that fishes might regenerate faster or slower in the different stages.

In Stage 1, subjects played up to 10 rounds with mostly cooperative bots and the resource had a low danger of depletion. In Stage 2 there was a crisis, the resource depleted in the 3rd round if not sooner. In Stage 3, subjects were assigned to either a low danger condition (similar to Stage 1) or a high danger condition (with mostly competitive bots), playing up to 10 rounds as well. In the low danger condition, the bot parameters were the same as in Stage 2. In the high danger condition, bots were much greedier than in Stage 1, but not as much as in Stage 2. For a more detailed description each Stage parameters', see Supplementary materials.

After finishing the task, subjects answered two final questions. First, one regarding their perception of the other players (bots) to assess if subjects believed they were playing with human players. Secondly, we asked them about their previous experience with these type of social dilemma games. Lastly, participants read information explaining the intentional deception of the experiment and gave their written consent (Appendix G).

Hypothesis

Stage 1:

H1) Glucose group cooperates more than placebo

H2) Prosocials cooperate more than proselves

Stage 3:

H3) *Low danger*: glucose group cooperates more than placebo

H4) *High danger*:

H4a) Glucose group cooperates more than placebo

H4b) No differences in cooperation levels between glucose and placebo groups

H5) Prosocials cooperate more than proselves in both *Low* and *High danger* conditions

Hypothesis 2 and 5, regarding the influence of social value orientation on cooperation, are predictions from the data obtained in previous studies that we expect to replicate. Prosocials will probably be more cooperative than proselves (Hypothesis 2), in accordance to the vast literature on SVO and cooperation in a commons (e.g. Balliet et al., 2009; Budescu, Au, & Chen, 1997; Joireman, Posey, Truelove, & Parks, 2009; Kramer, McClintock, & Messick, 1986; Liebrand, 1984; Liebrand & van Run, 1985; Loomis, Samuelson, & Sell, 1995; Parks, 1994; Roch & Samuelson, 1997). We also anticipate prosocials will again cooperate more after the crisis (Hypothesis 5), including in the High Danger condition, since they continue to

cooperate even if others are overusing the resource (Brucks & Van Lange, 2007; Joireman et al., 2009; Kramer et al., 1986; Loomis et al., 1995).

Hypothesis 1 (Stage 1) follows from the literature on glucose and decision-making, since there on glucose and cooperation. Since glucose-enriched subjects are more risk-averse and incur less in future discounting, we expect the glucose group to be more cooperative than the placebo (Orquin & Kurzban, 2016).

Hypothesis 3 and 4 (Stage 3) are mostly exploratory since there is no evidence that suggests how glucose will influence cooperative levels after a critical event and at different levels of danger of resource depletion (High vs Low danger).

Regarding Hypothesis 3 (Low Danger), we expect the glucose group to be more cooperative than the placebo given subjects who previously overused a resource use a low risk strategy: are more cautious initially, increase their harvests and then reduce them if resource size is low (Messick et al., 1983). Since glucose-enriched subjects are more risk-averse, we expect them to exhibit a safer and more cooperative strategy as well.

Concerning Hypothesis 4 (High Danger), we have two contradictory predictions. We expect the glucose group to be either more cooperative than the placebo, again revealing a safer strategy; or as competitive as the placebo, once they realize the resource is once more in danger of depletion and try "getting while the getting is still good" (Kramer et al., 1986).

Cooperation is operationalized through the following measures: the number of rounds played, number of fishes at the end of each stage, number of fishes left at the end of each round and individual restraint or efficiency measures.

III. Results

Participants

We tested 64 participants but 5 were excluded. Three subjects did not understand the task; one subject mistook the final round as the 4th instead of the 12th; and one participant who received the placebo drink later revealed having eaten an hour ago. This left 59 participants for analysis, out of which 12 exhibited a proself social value orientation and 47 a prosocial orientation. The small number of proself individuals did not allow for a statistical analysis and, therefore, the following results concern only the individuals with a prosocial orientation. For statistical analysis, we used IBM SPSS (version 23) software and used an alpha level of .05.

All 47 participants exhibited a native speaker comprehension of the Portuguese language, out of which 30 were females and 17 males. Their ages ranged from 18 to 60, with an average age of 35.96 years (*SD*=13.3). The majority of participants (87.3 %) had a graduate or higher level.

Drink quality

The quality of both drinks (placebo and glucose) was assessed by a Liking Index, composed by 3 Likert scale questions: 1) *How do you rate the general quality of the drink?* (from 1 "Low quality" to 7 "High quality"); 2) *How pleasant was the drink?* (from 1 "Not pleasant at all" to 7 "Very pleasant"); 3) *How difficult was to drink it?* (from 1 "Not difficult at all" to 7 "Very difficult"). A total score for drink quality was calculated by adding the scores of each item, with the last one being reverse-scored. This yielded a Drink Quality Score with a minimum of 3 and a maximum of 21. Since there was homogeneity of variances across drink groups, a rank test was used. A Mann-Whitney U test indicated that the quality of the placebo drink (*Md* = 16,5) did not differ from the quality of the sugary drink (*Md* = 16), $U = 253$, $p = .623$, $r = .07$.

Glucose manipulation

The distributions of glucose levels were not normal but homogeneity of variances was verified. A Mann-Whitney U test revealed that the blood glucose levels of participants who received the sugary drink and placebo differed significantly, $U = 25$, $p < .001$, $r = .78$. The blood glucose of participants in the glucose condition (*Md*= 112 mg/dL) was significantly higher than the level of participants in the placebo condition (*Md*= 92 mg/dL). The average time interval between the blood glucose measurement and finishing the drink was 14minutes (*SD*=2) and was never below 10 minutes.

Social Value Orientation

Social value orientation was assessed through the 6 primary items of the Social Value Orientation Slider Measure (Murphy, Ackermann, & Handgraaf, 2011). Each item presents 9 different distributions of imaginary money between the self and another player. The options varied the amount allocated to the subject and the "other player", thus allowing to categorize subjects' choices as more altruist, cooperative, competitive or individualist. To avoid item order effects, this task had two item sequences that were counterbalanced across subjects.

The set of responses yielded a single score for the decision maker (see Appendix H). This measure was reduced to nominal categories, for comparability with previous studies. The resulting SVO Slider angles range from -16.26º to 61,39º. Individual scores can be diminished to one of four categories: 1) Altruism: SVOº > 57.15º; Prosociality: 22.45º < SVOº < 57.15º; Individualism: –12.04º < SVOº < 22.45º; and Competitiveness: SVOº < –12.04º. Subjects with 22.45º < SVOº < 61,39º were categorized as prosocial and subjects with -16.26º < SVOº < 22.45º were categorized as proself. Our initial sample consisted mainly of prosocials, with 47 prosocials (46 prosocials, 1 altruist) and 12 proselves (11 individualists, 1 competitive). For the reasons stated previously, we analyzed only data from the prosocial individuals.

Harvest behavior

Stage 1

In Stage 1, there were no differences in the number of rounds played, with *Md* = 10 for both drink groups. This indicates subjects were cooperative enough to get to the final round. For the subsequent analysis, data from the 10 rounds was collapsed into 5 trial blocks in order to simplify data visualization and interpretation.

Regarding the number of fishes left in the pool at the end of each round, a 2 x 5 ANOVA with drink (glucose x placebo) and trial block as between-subject factors revealed a main effect of trial block $F(4,10) = 58.84$, $MSE = 7.29$, $p < .001$, $\eta^2 = .96$. As trials advanced, the nº of fishes left in the pool at the end of each round was lower than the previous. This was expected, since the average bot greed was 0.5, and two of the bots were set to slowly increase their greed. Nonetheless, the degree of the pool decay was higher than anticipated, indicating participants harvested above optimal level (10 resource units per player). No differences in this measure were observed as a function of drink, $F(1,10) = .139$, $MSE = 7.29$, $p = .717$, $\eta^2 = .01$. Hence, Hypothesis 1 – Glucose group will be more cooperative than placebo in Stage 1 – was not confirmed. No other differences were observed at this point.

Stage 3

Measures of cooperation

There were no differences in the number of rounds played in Stage 3 with *Md* = 10 for the four groups (2 drink x 2 danger). Even in the High Danger condition, where the bots were significantly greedier, most participants cooperated enough to get to the final round.

Regarding the nº of fishes at the end of each round, in the Low Danger condition, a 2 x 5 ANOVA with drink (glucose x placebo) and trial block as between-subject factors revealed main effect of trial block, $F(4,10) = 60.12$, $MSE = 8.99$, $p < .001$, $\eta^2 = .96$. With each trial, the

number of fishes left in the pool at the end of each round became lower. Again, this was expected due to the experimental manipulation. Results indicated a trend in the predicted direction for drink, F = (1, 10) = 4.52, MSE = 8.99, p = .059, η^2 = .31. Participants in the glucose group tended to leave more fishes in the pool at the end of each round than participants in the placebo group, indicating the former was more cooperative. This tendency favors Hypothesis 3, which stated the glucose group would be more cooperative than the placebo, in both danger conditions of Stage 3.

Concerning the nº of fishes at the end of each round in the High Danger condition, a 2 x 5 ANOVA with drink (glucose x placebo) and trial block as between-subject factors revealed main effects of drink, F(1,10) = 5.49, MSE = 11.49, p = .041, η^2 = .35 and trial block, F(4,10) = 47.02, MSE = 11.49, p < .001, η^2 = .95. As can be seen in Figure 3.1, the nº of fishes at the end of each round was lower as trial blocks progressed but was significantly higher in the glucose group, indicating they were significantly more cooperative than the placebo group.

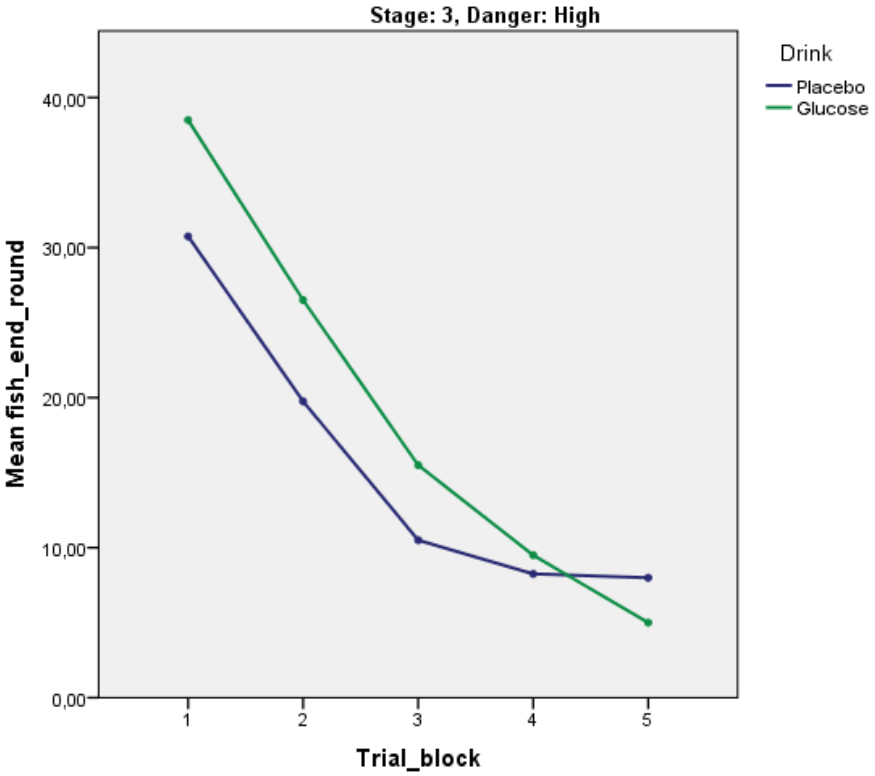

Figure 3.1 Mean fishes at the end of each round, per trial block, as a function of drink manipulation in the High Danger condition of Stage 3.

These results support Hypothesis 4a), which stated we expected the glucose group to be more cooperative than the placebo in Stage 3.

Measures of efficiency

Respecting the nº of points at the end of each round in Stage 3, no comparisons were made between the two danger conditions (High and Low) since they are not comparable. Within each danger condition, no differences in the total points were observed between drink groups. No differences in the individual efficiency measure were observed in the Low Danger condition. In the High danger condition, a 2 x 5 ANOVA with drink (glucose x placebo) and trial block as between-subject factors revealed an interaction between trial block and drink, $F(4, 10) = 6.52$, $MSE = .01$, $p = .008$, $\eta^2 = .72$. This interaction is depicted in Figure 3.2.

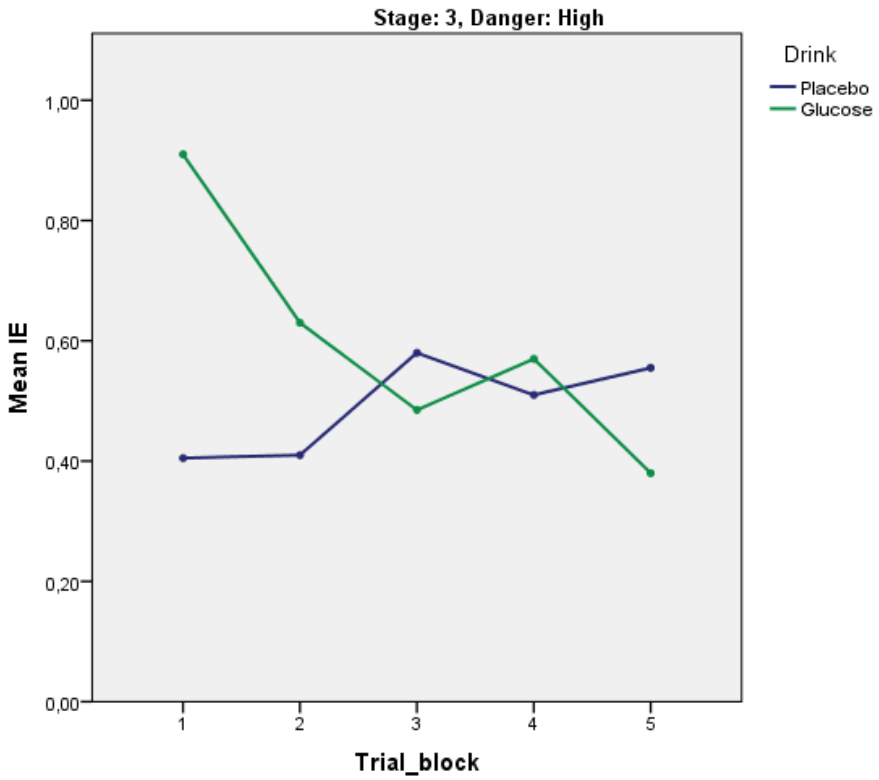

Figure 3.2 Mean individual efficiency per trial block as a function of drink manipulation, for the High Danger condition of Stage 3.

The glucose group was highly efficient in the initial trials but became less efficient as trials progressed, whereas the placebo group began with low efficiency and slightly increased it as trials advanced. Results indicate a trend in the predicted direction for drink, $F(1,10) = 4.71$, $MSE = .01$, $p = .055$, $\eta^2 = .32$. That is, generally the glucose group tended to be more efficient than the placebo, which again supports Hypothesis 4a.

Stage 1 and Stage 3 (Low danger)

No *a priori* hypothesis were established regarding subjects' harvest behavior in the Stages 1 and 3, and the further analysis was exploratory. To examine the effect of the crisis experienced in Stage 2 on subjects' harvest behavior, we compared only Stage 1 with the Low Danger condition of Stage 3, given both had the same settings (bots had the same greed). The fact that in the High danger condition bots were much greedier made it impossible to compare with Stage 1.

Regarding the nº of fishes at the end of each round, a 2 x 5 x 2 ANOVA with drink (glucose x placebo), trial block and Stage (Stage 1 x Stage 3 Low danger) as between-subject factors revealed a main effect of Stage, $F(1, 20) = 7.38$, $MSE = 8.14$, $p = .013$, $\eta^2 = .27$. After experiencing the crisis in Stage 2, subjects in the Stage 3 left less fishes at the end of each round than in Stage 1. This indicated subjects were generally less cooperative after experiencing the crisis. Results indicated a trend interaction in the predicted direction between drink and stage, $F(1,20) = 3.35$, $MSE = 8.14$, $p = .082$, $\eta^2 = .14$. After experiencing the crisis, the glucose group maintained harvest behavior similar to Stage 1, but left slightly less fishes at the end of each round. The placebo group tended to harvest more during Stage 3, leaving less fishes at the end of each round. Taken together, this indicates that in a post-crisis context, when there is Low Danger of resource depletion, subjects tend to be more competitive and that this effect tends to be stronger for the placebo group.

As to the individual efficiency, a 2 x 5 x 2 ANOVA with drink (glucose x placebo), trial block and Stage (Stage 1 x Stage 3 Low Danger) as between-subject factors revealed a trend interaction between drink and Stage, $F = (1, 20) = 3.20$, $MSE = 0.02$, $p = .089$, $\eta^2 = .14$. The glucose group tended to have higher efficiency in Stage 3 than Stage 1 (Figure 3.3B), while the opposite was true for the placebo group, which had a lower efficiency in Stage 3 (Figure 3.3A). Interestingly, the glucose group presented a decay in efficiency during the middle trials of both Stages, while the placebo group was relatively stable across trials.

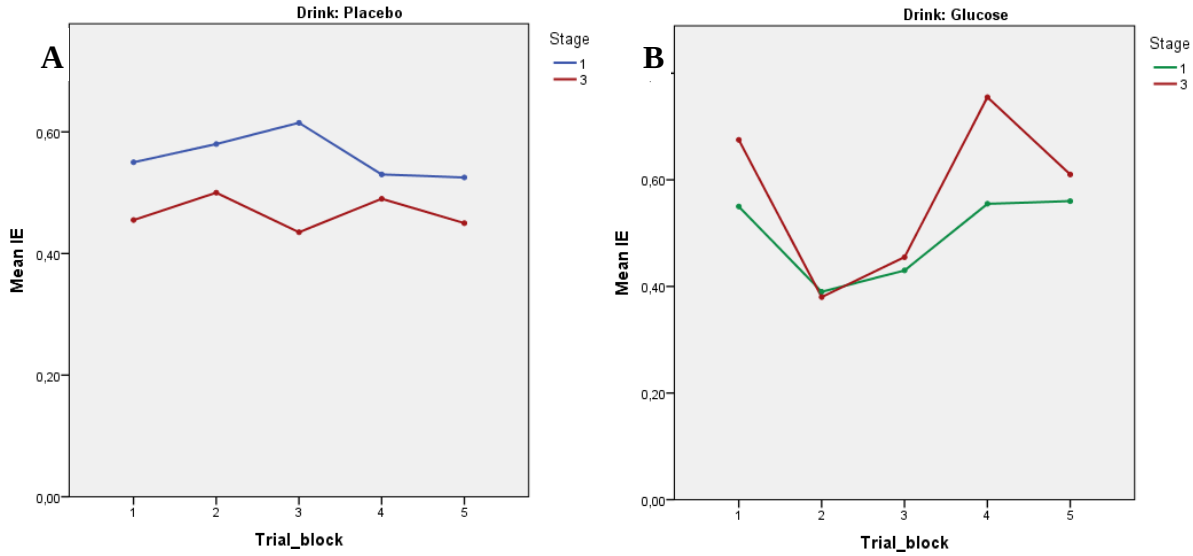

Figure 3.3 Mean individual efficiency per trial block in Stages 1 and 3, for the placebo (A) and the glucose group (B).

Bot manipulation

To verify if subjects believed they were playing with human players, we asked them this indirectly through the following question: *At least one of the players was a bot (pre-programmed player). Please select which one(s).* Subjects could select as many players as they wanted or *I don't know*. We considered the manipulation to be successful if subjects selected *I don't know* or just one player. The more players they selected, more likely it was they did not believe they were playing with human players. The majority of participants selected either one of players to be a bot or "*I don't know*" (95.7%), so we considered the manipulation successful.

Previous dilemma experience

Previous experience in these types of social dilemmas was assessed by asking at end of the experiment: *The game you just played is a version of a social dilemma. What is your level of experience or familiarity with these types of social dilemma games?* (from 1 "No experience" to 7 "A lot of experience"). Overall, participants reported to have an average experience with social dilemma games (*Md*=4, *Mo*=5).

IV. Discussion

Interpretation of results

We can summarize our results into three main findings. First, participants in the glucose group were generally more cooperative and more efficient in managing a resource after a crisis, especially when the resource was in higher danger of depletion. Secondly, the crisis seems to have a positive effect on individual efficiency in a subsequent stage for the glucose group, with the opposite being true for the placebo group. Thirdly, the glucose manipulation seems to have elicited different resource management strategies. The placebo group appears to be consistently less efficient than the glucose group. The glucose group seems to be as or more efficient in initial trials, reducing efficiency in the middle trials and recovering efficiency levels towards the end (reducing them again in the final rounds). In other words, the efficiency of the glucose group resembles a "zig-zag" pattern with its peaks and dips, while a straight horizontal line better describes the placebo group's efficiency. We now present a more detailed description of subjects' behavior for each Stage.

In Stage 1, and contrarily to our initial hypothesis, no significant differences were observed. The effect of the glucose manipulation was observed only after the crisis, in Stage 3 and its magnitude was greater in the High Danger than the Low Danger condition. Although there were no differences between drink groups in cooperation or efficiency indexes in Stage 1, an interesting pattern emerged in both individual restraint and efficiency measures. Both the placebo and the glucose group started off with the same level of restraint (0.28) and efficiency (0.55) but the glucose group decreased IR and IE in the middle trials (lower than the placebo group), increasing them again in the final rounds. The placebo group displayed a steady increase, but still ended with lower IR and IE than the glucose group in the final rounds. This pattern is again present in the Low Danger condition of Stage 3. To put these results in perspective, we need to consider that perfect efficiency would receive a score of 1 and a

sustainable restraint pattern would receive a score of 0.5. Therefore, our participants were far from an optimal harvesting pattern.

For Stage 2, we did not present any data since there were at most 3 rounds due to the high greed of all the other bots. Consequently, subjects' behavior would be uninformative since they would only realize the resource was in danger when it was too late. Some subjects displayed genuine expressions of surprise at Stage 2: "they [other players] are idiots, they are gonna end with all the fishes" or "this jo [bot jo827] is really greedy". Some subjects even showed embarrassment and were apologetic for the Stage ending so soon, as if taking most of the responsibility for the early depletion.

In the Low Danger condition of Stage 3, participants in the glucose group tended to leave more fishes in the pool at the end of each round than participants in the placebo group, indicating the glucose group seemed to be more cooperative than the placebo. Although there were no observable significant differences in the efficiency measure under the Low Danger condition, the pattern of results of the glucose and placebo groups was quite different. The glucose group began with higher efficiency (average IE of 0.68), had a sharp decrease in the middle trials (average IE of 0.42) and again recuperated in the final trials (average IE of 0.69). The placebo group maintained a constant efficiency level throughout all trials, with an average IE of 0.47. Although there were no differences in individual restraint, a somewhat similar pattern was observed: the placebo group slowly increased its IR whereas the glucose group again exhibited a decay and then an increase in IR.

The High Danger condition of Stage 3 was the one where most significant differences emerged between drink groups. There was a significant interaction between drink and trial block. The glucose group was very efficient in initial trials (average IE of 0.91) and lowered steeply as trials progressed. Contrarily, the placebo group started with much lower efficiency levels (average IE of 0.41) and slightly increased it over time. Moreover, there was a main

effect drink regarding the number of fishes left at the end of each round, which was significantly higher in the glucose group, indicating they were significantly more cooperative than the placebo group. Although we observed no differences in individual restraint, the pattern of results was again quite different between drink groups. Here, the glucose group began with moderate restraint levels (average IR of 0.48), maintained it in the middle trials and decreased it in the final rounds (average IR of 0.38). The placebo started with very low restraint (average IR of 0.27) and increased it steadily, ending with an average IR of 0.56 in the final rounds.

To examine the effect of the crisis experienced in Stage 2 on subjects' harvest behavior, we compared Stage 1 with the Low danger condition of Stage 3. Participants in Stage 3 (Low Danger) were generally more competitive than in Stage 1, leaving less fishes at the end of each round. However, this main effect of Stage is mainly due to the placebo group. Additionally, there was a trend interaction in the predicted direction between drink and stage. After experiencing the crisis, the glucose group maintained a similar the harvest behavior displayed in Stage 1. Conversely, the placebo group tended to harvest more during Stage 3, leaving less fishes at the end of each round. Regarding their resource management efficiency, the crisis seems to have a different impact in participants with different glucose levels. The glucose group tended to increase their efficiency from Stage 1 (average IE of 0.5) to Stage 3 (average IE of 0.58), adjusting their behavior in light of the crisis of Stage 2. Conversely, glucose deprived participants had a tendency to have lower efficiency from Stage 1 (average IE of 0.56) to Stage 3 (average IE of 0.47). For the placebo group we observe a steady efficiency level in both Stages 1 and 3 while for the glucose group we observe, for both Stages, initially higher efficiency, lower in the middle trials, recuperating again in the final ones.

Our finding that the glucose group is generally more cooperative and efficient in managing a resource after a resource crisis matches with our predictions from the literature on

glucose and decision-making in terms of risk and future discounting. That is, the increased cooperation in the glucose group may be a consequence of greater risk aversion or less future discounting (by placing greater value in larger rewards in the future than in smaller and more immediate ones). These results also support the literature on the effects of glucose on self-control behaviors, such as impulsivity, attention control, emotion regulation, crime and aggression, stress coping, smoking and alcohol consumption, with higher levels being associated with more self-control (see Gailliot & Baumeister, 2007 for a review). In the FISH task, the glucose group increased cooperation may reflect their ability to restrain from harvesting in order to preserve the resource longer.

Surprisingly, no significant differences between glucose and placebo emerged during Stage 1 and we only observed differences after the crisis (Stage 3) and with greater magnitude in the High Danger condition. For Stage 1 we expected the glucose group to be more cooperative and efficient than the placebo. The fact that no differences were observed at this point suggests that Stage 1 was mostly exploratory and that, after the crisis in Stage 2, the glucose group was able to adapt to new scenario while the placebo did not.

In Stage 3, the Low and High Danger conditions had the same regeneration rate, varying only the bots greed and greed spread, which were increased in the High Danger condition. In the High Danger, we observed larger differences between drink groups in cooperation and efficiency indexes, comparing to the Low Danger condition. The High Danger condition requires greater adaptation or change in subjects' harvest behavior for a successful resource management than the Low Danger condition. The glucose group tended to be more cooperative than the placebo in the Low Danger condition and was significantly more cooperative and efficient in the High Danger condition. This suggests the glucose group was better able to adapt to the other players increased harvests in the High Danger condition, by reducing their harvests.

When we compare Stage 1 and 3 (only Low Danger) we observe the glucose group became more efficient while the placebo reduced their efficiency, although the major difference was in initial trials. Since the Stage 3 (Low Danger) had the same settings as Stage 1, this suggests that the crisis event was perceived differently by drink groups and was perhaps more salient for the glucose group.

Regarding the third main finding on the different resource management strategies used by the glucose and placebo groups, we can establish a parallel with previous studies. The placebo group was consistently less efficient than the glucose group, with the latter exhibiting a ziz zag pattern. Messick et al., (1983) observed that subjects that had previously experienced resource overuse, were, in a second session, initially more cautious but then greatly increased their harvests and, when the pool size was very low, reduced them. This is a relatively safe risk strategy and corresponds to the data pattern of our glucose group.

Overall, subjects were much more competitive and less efficient than we expected, as revealed by the number of fishes left at the end of each round and the efficiency measure. Nevertheless, most subjects did not deplete the pool before the final round (round nº 10), demonstrating they understood the need to let the game continue but with some, particularly the placebo group, not changing their behavior in accordance to the other players' harvests. The low cooperation in general is even more striking once we consider all participants exhibit a prosocial value orientation.

Previously we reflected upon our findings in detail and in relation with previous studies. The following section examines our results in light of the theoretical framework that guided this work. According to the Social Heuristics Hypothesis (SHH), and reinforcing Simon's theory on human docility, humans tend to cooperate intuitively (Rand et al., 2014; Zaki & Mitchell, 2013). This idea is supported by several empirical studies on human cooperation in

social dilemmas (e.g. Rand, 2016; Rand & Nowak, 2013). The SHH considers cooperative decision-making within the dual-process framework, proposing a connection between intuition and cooperation. SHH suggests that, in repeated games when there is the perspective of future consequences of the present action, both intuition and deliberation promote cooperation. Promoting intuitive processing leads to cooperation because we cooperate intuitively; and promoting deliberation leads to the rational strategy in such contexts, which is strategic cooperation. In our study, and going back to the literature on glucose and decision-making, glucose enrichment induces deliberative processing to override intuition while glucose deprivation promotes intuitive processing. Thus, and according to the SHH, no differences are expected between our glucose group (more deliberative) and our placebo group (more intuitive). Although they incur in different decision processing styles, both are expected to yield cooperation in repeated games such as the FISH task. As predicted by the SHH, no differences between placebo and glucose groups were observed at Stage 1 our task. However, after the critical event, the glucose group tended to be more cooperative than the placebo when there was a Low Danger of resource depletion; and was significantly more cooperative and efficient than the placebo under High Danger of depletion. The first observation suggests the glucose group may have perceived the crisis as a more critical event than the placebo. The second observation indicates the glucose group adapted their behavior in function of the overharvesting of the other players while the placebo did not. The SHH does not account for this phenomena and we believe our results could possibly be informative for this theory. It is our belief that the suggested link between intuition and cooperation is too simplistic. In our view, there is one step missing: intuition promotes heuristic processing which may, in turn, promote cooperation or not. That is, the heuristic used depends on the conditions of the social dilemma.

For instance, in some commons the most salient heuristic may be the **equal division heuristic**, which is a readily evoked rule that prescribes that whatever is being allocated should be divided equally among the participants (Allison & Messick, 1990). In other words, it is a simple choice rule easy to apply that is socially defensible as fair allocation. This idea is supported by Roch, Lane, Samuelson, Allison, & Dent, (2000) study, which proposes a 2 stage model of resource overconsumption. They propose that members of groups sharing resources: 1) first anchor their consumption choices on the equal-division" heuristic; 2) and then, given sufficient cognitive capacity, adjust their choices in a self-serving direction. As in the dual process framework, we first use intuitive processing and, if sufficient cognitive resources and motivation, deliberation overrides the previous step.

However, promoting an intuitive processing type may not necessarily evoke the previous heuristic. For example, we would expect that individuals with high social dominance, who desire to dominate others and prefer hierarchical to equal relations, would not resort to this heuristic, possibly because they did not integrate this as a heuristic in the first place.

As observed in our results, the placebo group that possibly incurred in a more intuitive processing, did not resort to the equal division heuristic. Many factors may have caused this, namely, seeing other players overharvesting, not knowing which was the equal division rule, etc. Other social heuristics may be used instead such as the previously described tit for tat. For example, Rand & Nowak, (2013) concluded from their study that, in repeated settings, it is intuitive to reciprocate: cooperate if others have cooperated and defect if others defected, which is the definition of the tit-for-tat. Our findings seem to go somewhat in line with this in the sense that, in the High Danger, the placebo group (possibly more intuitive) was more competitive, reciprocating the greed of other players. Or, in other words, they conformed to the overharvesting behavior of some players, replicating previous findings (Kramer et al., 1986; Messick et al., 1983; Rutte & Wilke, 1984; Schroeder et al., 1983). However, in the FISH task

(High Danger of Stage 3) the behavior of other players was heterogeneous: one bot harvested at a suboptimum level, another at optimum and the other two overharvested. The higher competitiveness of the placebo group may indicate participants conformed to the overharvesting of some players. This would strengthen Rutte & Wilke, (1984) findings: even if people are in a privileged position (leaders deciding how much to allocate to each participant), they conform to what they perceive to be the group norm. In their study, leaders who previously experienced a resource being overused as "normal" group members again overused the resource when they became leaders. Thus, one possible explanation for our findings is that the placebo group conformed to the perceived group norm.

Another explanation for these findings is participants followed a social heuristic of **imitate the majority**, following the behavior of the two bots that were overharvesting. This heuristic states to look at a majority of people in your peer group, and imitate their behavior (Gigerenzer, 2008). However, we believe that the placebo group mostly followed a **imitate the successful heuristic** that says to look for the most successful person and imitate his or her behavior (Gigerenzer, 2008). The task's goal was for each subject to get as many points as possible at the end of the task. Participants may have perceived the greediest bot [jo827] as the most successful and guided their behavior by his. Some subjects even reported using the strategy of trying to get at least one more fish than the bot jo827, which reinforces this idea. Another "golden rule" some participants reported to use was stop harvesting once the resource turned grey, demonstrating they understood the basic idea of the task.

Now we will focus on how some of the individual variables (reviewed in chapter 2) which might explain participants' behavior in the FISH task: participants' previous dilemma experience, gender and social value orientation and expectations.

We asked participants about their **previous dilemma experience** since experienced players perform better in the commons dilemma (Gifford & Hine, 1997; Hine, 1990). However, we believe that the reported previous dilemma was highly inflated. Several subjects later revealed they understood the question concerned their experience with social dilemmas in daily life (e.g. at work, within their social circle, etc.) and not regarding actual experience with social dilemma games. The reported previous experience was "moderate" (*Md* = 4 out of a 1-7 Likert scale) but we actually believe it was much lower, since this contact with game theory and social dilemmas is common only among psychology and computer science degrees. Thus, we consider our sample was generally naïve to this sort of economic games, idea favored by our global finding of overharvesting behavior.

Regarding participants' **gender**, our sample was mainly composed of women (approximately 64%). Although no significant sex differences in cooperation in social dilemmas were reported in a recent meta-analytic review, it seems that men become increasingly more cooperative than women as rounds advance (Balliet, Li, et al., 2011). Since our sample had a larger percentage of women, this could have introduced some unwanted variability. This study by Balliet, Li, et al., (2011) also revealed that men cooperate more than women in same-sex interactions but women are the more cooperative gender in mix-sex interactions. To avoid confounders, participants were given a random code (e.g. lb482) that did not identified them as males/females.

Concerning participants' **social value orientation** (SVO), the analyzed sample consisted only of individuals with a prosocial orientation since there was not enough proself oriented individuals to compare with. We know that in commons dilemmas, prosocials harvest significantly less than do proselves (e.g. Balliet et al., 2009; Budescu, Au, & Chen, 1997; Joireman, Posey, Truelove, & Parks, 2009; Kramer, McClintock, & Messick, 1986; Liebrand, 1984; Liebrand & van Run, 1985; Loomis, Samuelson, & Sell, 1995; Parks, 1994; Roch &

Samuelson, 1997). Although the distribution of prosocials and proselves in our sample did not allow for any statistical comparisons, the initial data seems to go in the predicted direction with prosocials being more cooperative than proselves. However, a larger sample is required to replicate this effect of prosociality and to verify how different SVO modulates post-crisis behavior in both High and Low Danger conditions. We expect prosocial individuals to be always more cooperative than proselves, even when the resource is in danger of depletion, replicating previous findings (Brucks & Van Lange, 2007; Joireman et al., 2009; Kramer et al., 1986; Loomis et al., 1995). One could argue that since prosocials have greater trustworthiness and higher expectations that others will reciprocate cooperation (Balliet et al., 2009; Dawes et al., 1977; Kramer et al., 1986; Liebrand, 1984) the crisis probably consists in a greater violation of expectations for prosocials. Nevertheless, we do not expect this to shift results in the direction of prosocials becoming as or more competitive than proselves, since the only scenario examined so far in which prosocials act like proselves is under conditions of noise (Brucks & Van Lange, 2007).

Limitations

This section addresses the three major limitations of this project related to the sample, glucose manipulation and measurement, and the experimental task.

Our sample size was much lower than required for robust statistical testing, meaning the statistical analysis allows only looking at tendencies in the data. Moreover, the sample was biased towards female college students, leading to unequal representation of gender and education level of the population. Additionally, all of our participants were volunteers and gained no reward for completing the task. Volunteer subjects have certain characteristics (e.g. Rosnow & Rosenthal, 1976) and this certainly introduced a bias towards prosocial individuals in our sample, since prosocials are naturally more cooperative and volunteering.

We recruited participants through the "snowball" sampling method, asking each participant to encourage other people to participate as well. This sampling method is most useful for difficult to access populations and is mainly used in qualitative research (Atkinson & Flint, 2001). Although this method can have several advantages, it creates a selection bias, since participants are not randomly selected and depend on the referrals of the first participants, thus limiting to generalize the findings to the population. To overcome these shortcomings, the experimenter recruited people from different academic backgrounds, age groups and socio-economic status who, in turn, recruited future participants from their social networks. Consequently, our sample became more diverse and more representative of the general population than the usual samples comprising only psychology college students.

Concerning the glucose manipulation, participants were tested at different times of the day. Blood sugar levels fluctuate during the day (Krishna, Kota, & Modi, 2013) and this might have introduced some unwanted variability. However, we controlled for this by asking all participants to fast for 3 hours before the experimental session, as in previous studies (Bos et al., 2012; Dickinson et al., 2014). Some participants in the placebo group reported their last meal was between 2-3h ago instead of at least 3h, which possibly mitigated some differences in glucose levels between drink groups. An additional confounder for the glucose manipulation relates to participants' diet and physical activity, which influence glycemic metabolism and control (e.g. Mikus et al., 2012; Rizkalla, Bellisle, & Slama, 2002). Initially our design was double-blind in regard to the glucose manipulation: participants were unaware of a placebo condition and the experimenter did not know which drink was the sugar-rich. A third party was asked to code the drinks with A or B and write the correspondence between drink and letter in an envelope, to be opened only after data analysis. However, during data collection the experimenter became aware of which drink corresponded to each code, since the experimenter measured and registered the participants' blood glucose levels. During the experimental

sessions, the presence of another person in charge of the glucose measurements is required to assure a double-blind design.

Glucose measurement also poses a problem, since we are only inferring brain glucose levels through glucose levels in the bloodstream. This measure might not accurately represent changes in the brain, however, it is known that brain glucose levels are approximately 15–20% of blood levels (Dunn-Meynell et al., 2009). An additional constraint was only measuring glucose levels once. Ideally, we would have measured blood glucose levels twice: before ingesting the drink and 10-12min after, allowing us to verify if participants' blood glucose levels significantly increased in that time period. Two main reasons forced us to make only one measurement: added cost (additional paper stripes and lancets) and increasing discomfort for participants. Despite glucometers not being as reliable as laboratory analysis for estimating blood glucose, they are a low-cost and less time-consuming tool.

As to the FISH program, the task was not exactly the same for all subjects, although we programmed bots equally for all (greed parameters). For example, in Stage 1 bots had an average greed of 0.5 (together they took the optimal amount of fishes per round) and the resource decay varied only due to the participants harvest behavior. Although this results in different game patterns for different subjects, this is common in iterated social dilemma paradigms and seems to be a better solution than the resource feedback procedures used in previous research (Kramer & Brewer, 1984; Messick et al., 1983; Rutte & Wilke, 1984). In these studies, participants harvest as many items as they wanted and were given feedback about the status of the resource. This means that subjects who harvested very different amounts could receive the same resource feedback, which is likely to introduce some confounders.

To induce a resource crisis in Stage 2, we lowered the replenishment rate (from a factor of 2 to a factor of 1.5) and also increased bots' greed, otherwise they would adjust their harvests by taking very little or none of the resource. Our goal was actually to maintain bot behavior

constant (social environment) and vary only the replenishment rate instead (physical environment). By doing so, we would be able to separate the response to the crisis (created by external factors) from the response to the behavior of other group members. Since the task parameters did not allow for manipulating only the physical environment, we had to change the social environment (bot behavior) as well.

Another potential problem was subjects not believing they were playing with others and realizing they were playing with a program. We controlled for this by asking them: *At least one of the players was a pre-programmed bot. Please select which one(s).* The rationale is the more players they select, the stronger the belief they were playing with bots and not humans. If they selected the option *I don't know* or one player, we considered subjects believed they were playing with other participants. The majority of subjects (95.7%) chose one of the bots or *I don't know*, so we considered the manipulation successful. However, the question framing might have been misleading, given some participants reported they did not know they could select more than one, although it was explicitly stated.

For all stages, the predictability of action parameter was always set to be regular, which makes bots' behavior seem less human but brings the advantage of standardizing the bots' behavior across subjects. To avoid the loss of credibility in other players being human, we inserted a short message in the instructions explaining the table with information about other players had a slight delay because it was updated regularly and simultaneously. Still, this created a discrepancy between the harvest speed of participants and bots, with the latter being much slower. One possibility to overcome this obstacle is allowing participants to only harvest 1 fish per second (at the same pace as the bots do).

Finally, we should consider if we are really looking at cooperation in our study. Here we consider the social science's definition, of cooperation as behaviors that maximize common profit (Vohs & Baumeister, 2007). The commons dilemma definitely allows operationalizing

cooperation, among other variables of interest. The commons dilemma can be seen as a cooperation/competition phenomenon; as a coalition and intragroup power phenomenon; as a communication and group information-processing phenomenon; as a problem-solving and group adaptation phenomenon; as a complex reinforcement and reward-guided phenomenon; and as an analog of experimental crisis (Edney & Harper, 1978a). The question remains: participants refraining their harvests, and paying the immediate cost of having less fishes now in order to preserve the resource for as long as possible, reflects cooperative behavior? To answer "yes" participants need to be motivated towards the goal of the task: to get as many points as possible in the end. We believe participants were motivated but future studies should give a monetary reward at the end of the game that depends on their performance to assure motivation (e.g. give 1/8 euros of the points they gather).

Implications for future research

Firstly, it would be interesting to add another post-crisis condition in the FISH task. Our conditions of Low and High Danger aimed to represent different patterns of resource use: one closer to optimal use and the other to overuse, respectively. A third post-crisis condition of resource underuse could bring some additional insights. We anticipate the results would largely depend on the homogeneity of others harvests. In this underuse condition, would the glucose group underharvest in order to avoid another crisis, exhibiting a risk averse behavior? Alternatively, would they realize they could harvest a little more than the others without risking depletion? Would the placebo group conform to the behavior of other players or would they become more competitive due to their increased risk seeking? Another variable that will possible be determinant for the post-crisis behavior is group identification, since a stronger group identity has been shown to increase cooperation in a commons (Baird, 1982; Brewer & Kramer, 1986; Kramer & Brewer, 1984).

Secondly, a follow up study should consider informing the participants about the optimal strategy, to avoid confounders arising from exploration of the best strategy. In the present research, we only told participants that *the goal was to get as many points as possible at the end of the game and this implied letting the game continue for as many rounds as possible*. With the observed low cooperation levels, especially since our data concern only prosocial individuals, we consider the above information was insufficient to promote better resource management. Future studies should consider giving the exact optimal strategy (in terms of how many fishes each player should take per round) and observe how participants deviate from this strategy. It would be very interesting to observe how participants with different glucose levels deviate from said strategy under the different conditions of resource use.

Thirdly, future research replicating a resource crisis in dilemmas such as the FISH task should attempt to create the critical event by changing the physical environment (replenishment rate of the pool) and not the social behavior (other players' behavior). Therefore, results would reflect participants' response to the crisis (created by external factors), separating it from the response to the behavior of other group members.

Additionally, future studies should consider manipulating the said optimal strategy: true optimal, underharvest, overharvest. Imagine the optimal strategy is for each fisher to take 10 fishes per round. This would be the information given in the true optimal condition. In the suboptimal information conditions – underharvest and overharvest – the experimenter would say the optimal strategy is for each fisher to take 6 or 14 fishes per round, respectively. It would be interesting to see how participants under different glucose levels behave across conditions. When the true optimal strategy is given, would the placebo and glucose groups stick to it? Would they adjust their harvests once they realize they were given the suboptimal strategy? An additional interesting manipulation concerns the heterogeneity/homogeneity in other players'

harvests. Will the different pressures for social conformity (high pressure in homogeneity and low in heterogeneity conditions) determinate if participants go outside the "instructed optimal strategy"? Would the current level of blood glucose have an effect? This would be a 3 x 2 x 3 x 2 design with resource use (optimal, suboptimal, overuse), drink (glucose vs placebo), strategy (underharvest, true optimal, overharvest) and variability in others harvests (high vs low). Since acceptance without full evaluation is at the core of this docility mechanism that supports the notion of intuitive cooperation, would the placebo group adhere to the suboptimal strategies when the pressure to conform is high? How would the level of resource use determinate their behavior? Future research should address these questions. Given the previous experimental design is too complex, with excessive independent variables and levels, future research would probably benefit splitting it by manipulating less variables in each study.

Future research would also benefit from measuring other variables such as social dominance orientation (SDO), risk seeking and social desirability. SDO is the extent to which one desires that one's group dominates and becomes superior to other groups, reflecting whether one generally prefers such relations to be equal or hierarchical (Pratto, Sidanius, Stallworth, & Malle, 1994) An individual's levels of SDO may influence their contribution to social equality or inequality and is negatively correlated with empathy, tolerance, communality and altruism. The SDO probably is inversely correlated with the SVO and individuals who score higher in the social dominance measure will probably be more competitive in the task. The few studies on the effects of glucose on risk suggest that glucose deprivation increases risk seeking (Levy et al., 2013; Symmonds et al., 2010). However, the individual's tendency for either risk seeking/aversion will probably be the starting point and the glucose manipulation may shift it up or down. Finally, social desirability is the tendency for individuals to portray themselves in a generally favorable fashion (Martin Guha, 2010). Considering participants' choices in the FISH task were public, knowing others could see their responses possibly

induced participants who score high in social desirability measures to cooperate. The original measure created for a non-pathological population by Crowne & Marlowe, (1960) or one of the more recent short-forms (e.g. Fraboni & Cooper, 1989) are appropriate to assess this.

Future studies should also seek to include other behavioral measures like reaction times, as well as electrophysiological ones, such as pupillometry and eye gaze, measured with eyetracking; and brain rhythms, using electroencephalogram (EEG). Response times would allow for stronger inferences about the processing style dominating participants decisions: more intuitive if reaction times are shorter and more deliberative if they are longer. Pupillometry may provide interesting correlates of participants' surprise during the crisis in Stage 2, since there is evidence suggesting increased pupil dilation signals surprise (Preuschoff, 't Hart, & Einhäuser, 2011). We would expect this only if participants were truly motivated for the task. Increased pupil dilation is also associated with higher cognitive load (Granholm & Steinhauer, 2004). Having this in mind, we would expect our placebo group (higher cognitive load) to have greater average pupil dilation; and that prosocials had increased pupil dilation, comparing to proselves, during the crisis at Stage 2, since they have higher expectations of cooperation and the crisis would produce a greater error signal. Additionally, eye movements measured by eyetracking could reflect what is more salient in the task: the behavior of other players, the resource status, which player is the most observed, etc.

The EEG could be useful to look into brain rhythms, specifically the alfa (8-15Hz) and theta waves (4-7Hz). These waves have increased power when participants are in a glucose-enriched rather than fasting state (>8h) in the whole brain and are especially prominent in the frontal and parieto-occipital regions (An, Jung, Kim, Lee, & Kim, 2015). It would be an interesting neurophysiological correlate of cognitive load to observe higher power of alfa and theta waves in our glucose group in comparison to placebo.

Future studies should consider focusing on which heuristic is more salient. This probably depends on several situational variables (such as the tasks' social structure, group size, etc.) and individual ones, such as risk-seeking, previous dilemma experience, SDO and SVO, among others. Once more, we point out that our results concern only the effects of glucose on cooperation of individuals with a prosocial value orientation. Future research should look to include individuals with a proself orientation as well. As mentioned above, we expect that prosocials will cooperate more than proselves, replicating previous findings (e.g. Balliet et al., 2009; Budescu, Au, & Chen, 1997; Joireman, Posey, Truelove, & Parks, 2009; Kramer, McClintock, & Messick, 1986; Liebrand, 1984; Liebrand & van Run, 1985; Loomis, Samuelson, & Sell, 1995; Parks, 1994; Roch & Samuelson, 1997). No interaction between glucose levels and social value orientation is anticipated from the literature. However, it is likely that, when an intuitive processing style is promoted (by lowering glucose levels), the most salient heuristic for prosocials and proselves will differ. In sum, this new approach on the SHH not only accounts for our results but also may explain the observed differences between prosocials and proselves.

For further support of the heuristic hypothesis, it would be interesting to incorporate a social simulation approach, from the field of computation. The idea would be to run simulations with 4 bots programmed as we have before and one programmed to learn. This last bot would search for the optimal solution or strategy with the goal of obtaining the maximum number of points at the end of the game. This "learning bot" could be, in different simulations, programmed with different search algorithms for problem solving. For a bot/agent to solve a problem there are two main types of search methods: blind search and informed search (Russell & Norwig, 2010). The blind search does not use any additional information about the problem besides the problem definition itself whereas the informed search uses problem-specific

information, which drastically reduces the search process, rendering the search more efficient. The latter uses a heuristic function to estimate the cost of the cheapest path from the initial state to the final state (solution). Not strikingly, this definition of heuristic closely resembles the one provided by the social sciences. By creating different heuristic guided search algorithms, we could compare not only the bots' performance across search conditions (particularly, different heuristic functions) but also to model participants' behavior in such settings and compare it with the empirical data.

V. Conclusion

The purpose of this study was to understand how different glycemic levels influence our decision to cooperate in a post-crisis context. Our blood glucose levels fluctuate significantly during the day and this variability influences our decision-making. Therefore, the present work analyzed for the first time the effects of different blood glucose levels on human cooperative behavior in a social dilemma and explored the said effect after a critical event, a resource crisis.

We observed participants with higher blood glucose were more cooperative only in a post crisis context and mainly when under greater danger of resource depletion. Our findings do not imply a direct causal link between brain glucose and cooperation but instead that blood glucose levels influence decision-making processes, as demonstrated in previous studies; adding that it can influence cooperative decision-making in some contexts.

Reflecting upon our results, we suggest that lower blood glucose levels are associated higher cognitive load that, in turn, promotes an intuitive processing type, boosting the use of certain social heuristics. Future research should address which social heuristics are more salient in different post-crisis scenarios, under different blood glucose levels. Combining methods from Psychology, Neuroscience and Computation, thus integrating different areas of Cognitive Science, could expand our understanding on cooperative decision-making.

VI. References

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VII. Appendixes

Appendix A - Prisoner's Dilemma game description

In the game, two players choose to cooperate or defect and receive a payoff that depends upon the interaction of their choices. Each of the four possible outcomes is associated with a different payoff. The original payoff matrix used by Albert Tucker consists in the following: if both players cooperate (CC), each one receives 2€; if one cooperates and the other defects (CD or DC), the cooperator gets nothing and the defector receives 3€; if both players defect (DD), each earns only 1€. The studies we will present use this standard payoff matrix.

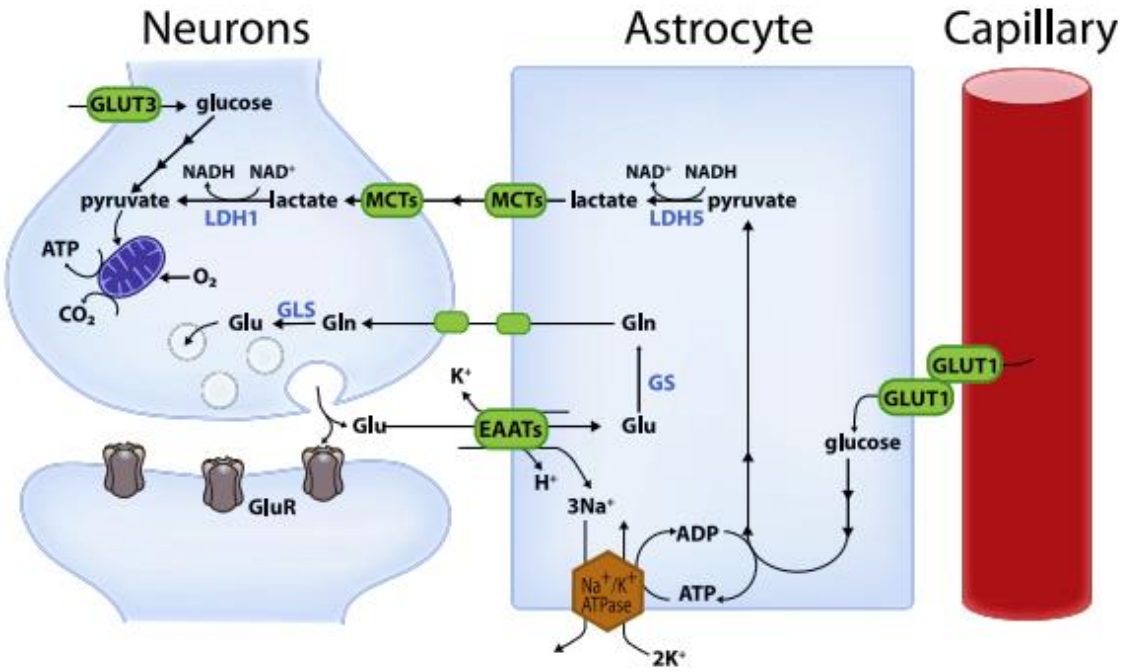
	C	D
C	2 2	3 0
D	0 3	1 1

Adapted from Payoff matrices in Wikipedia, n.d., Retrieved July, 14, 2016 from http:// commons.wikimedia.org/wiki/File:Prisoners_dilemma.png. Copyright by the Free Software Foundation.

Appendix B – Bot parameters

- Greed: (value from 0 to 1) 0 causes bots to take no fish, 0.5 causes them to fish at an exactly sustainable rate, and 1 causes them to take all fish possible;
- Trend: (stable, increasing or decreasing) a bot with a stable trend will behave the same way at the beginning and at the end of the simulation. A bot with an increasing trend will be as greedy as time goes by (while still being as greedy as specified on its Greed parameter, on average). A bot with a decreasing trend will be less greedy in later rounds.
- Greed spread: this parameter sets the bots' greed change over time
  - The lowest greed will be: base greed - (greed spread / 2)
  - The highest greed will be: base greed + (greed spread / 2)
  - The season-to-season increment or decrement is calculated by: (highest greed - lowest greed) / (number of seasons - 1)
- Predictability of action: can be erratic or regular. If erratic, bots behave non-deterministically. They may or may not act at any given moment of the simulation - adds to realism.

Appendix C - Schematic representation of the astrocyte-neuron lactate shuttle (ANLS)



Adapted from "Brain energy metabolism: focus on astrocyte-neuron metabolic cooperation," by M. Bélanger, I. Allaman and P. J. Magistretti, 2011, *Cell Metabolism, 14,* p. 729. Copyright 2011 Elsevier Inc.

Appendix D: Informed consent

Este estudo surge de uma colaboração entre as Faculdades de Psicologia, Ciências e Medicina da UL, supervisionado pelo Prof. Leonel Garcia-Marques e Profª Ana Sebastião. O objectivo deste projecto consiste em analisar o efeito de uma bebida açucarada na tomada de decisão. Esta sessão terá uma duração de cerca de **35 minutos**.

Vai começar por beber uma bebida açucarada e realizar uma tarefa de alocação de bens. De seguida, irá participar no **jogo online FISH** que está a ser desenvolvido no âmbito de um projecto das unidades curriculares de Teoria dos Jogos I e II. O jogo demora cerca de 10min.

Antes de começar o jogo, vamos medir o seu nível de glicemia usando um glucómetro – aparelho usado na diabetes. Para tal, faz-se uma pequena picada no dedo anelar/mindinho (usando uma lanceta) para expôr uma gota de sangue, o que pode causar um desconforto ligeiro. De seguida, usa-se uma tira de papel para absorver a gota de sangue e insere-se a tira no glucómetro. Segundos depois, obtém-se uma leitura do seu nível de açúcar sanguíneo. Cada participante irá usar uma lanceta diferente, de modo a assegurar que todo o material é completamente esterilizado.
Se sofrer de diabetes, hipoglicémia, hemofilia ou tiver dificuldades de coagulação sanguínea, pedimos-lhe que não participe para sua própria segurança.

A sua participação é voluntária, pelo que pode negar a sua participação ou, a qualquer momento, desistir. Contudo, se optar por desistir ou não responder a alguma questão, não poderemos utilizar os seus dados. As suas respostas são confidenciais.

Quando este estudo estiver terminado, se tiver alguma questão ou interesse em receber os resultados globais, por favor dirija-se a casqueiro@campus.ul.pt - email da investigadora.

Se compreendeu os seus direitos e pretende participar, assinale a caixa abaixo com "X".

☐ Compreendi e aceito participar

Obrigada!

Appendix E: Social Value Orientation task

INSTRUÇÕES

Imagine que foi aleatoriamente emparelhado com outra pessoa, que é alguém que desconhece e que o desconhece a si, ou seja, o anonimato será mútuo.

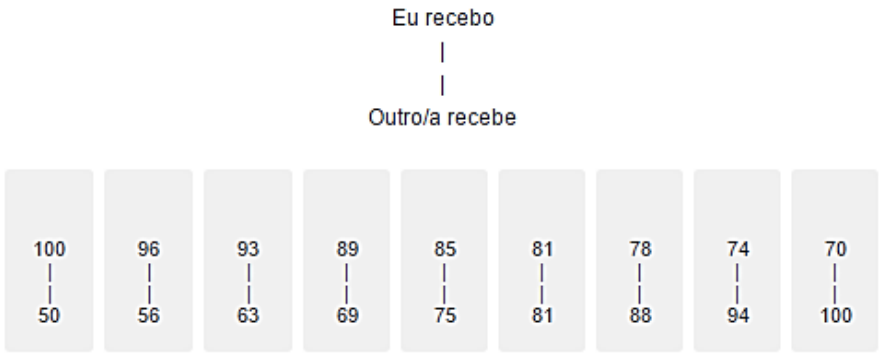
Tomará uma série de decisões acerca da distribuição de recursos entre si e a outra pessoa. Para cada uma das seguintes questões, por favor indique a distribuição que mais prefere **selecionando o botão abaixo desta**. Apenas pode selecionar uma para cada questão. As suas decisões resultarão em rendimento tanto para si como para a outra pessoa. Todas as suas escolhas serão completamente confidenciais.

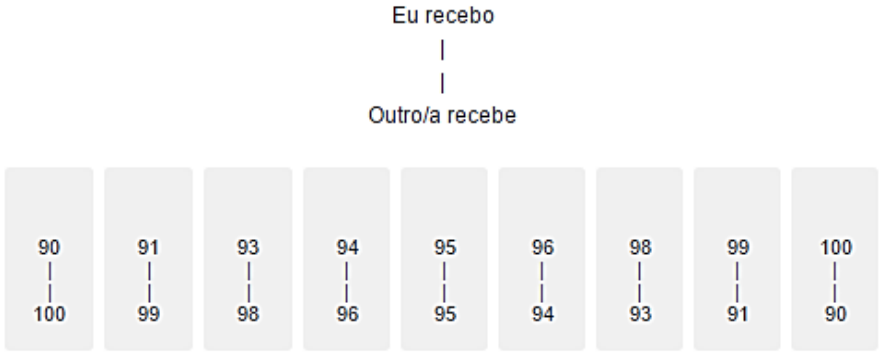
No exemplo abaixo, uma pessoa escolheu a distribuição de pagamento em que ela própria receberia 50€, e a outra pessoa anónima receberia 40€.

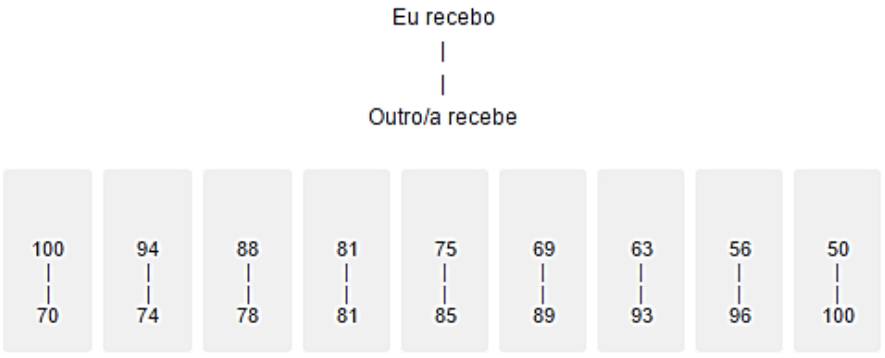
EXEMPLO

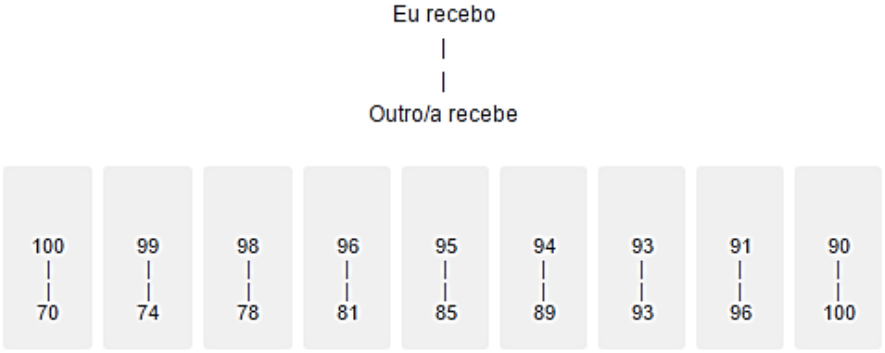
Eu recebo	20	25	30	35	40	45	50	55	60
Outro/a recebe	70	65	60	55	50	45	40	35	30
	○	○	○	○	○	○	◉	○	○

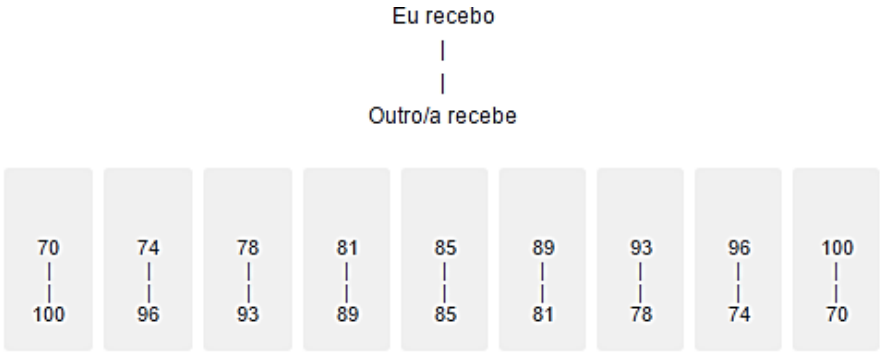
Não existem respostas certas ou erradas, trata-se apenas de preferências pessoais. Após tomar a sua decisão, **selecione a distribuição de dinheiro clicando no botão abaixo da sua escolha**. As suas decisões influenciarão tanto a quantidade de dinheiro que receberá, bem como a quantidade de dinheiro que o outro/a receberá, nesta situação imaginária.

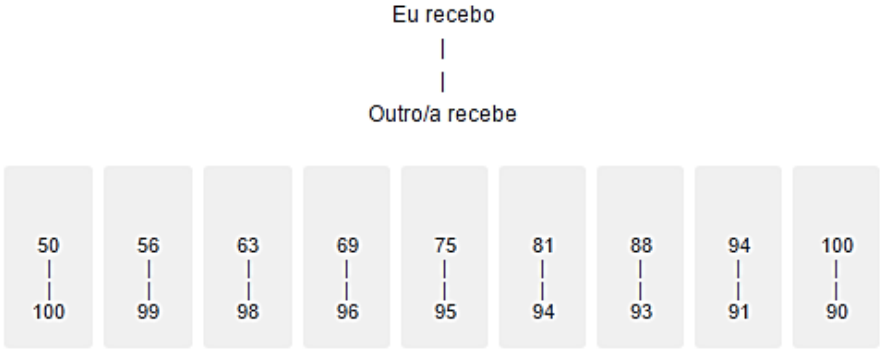


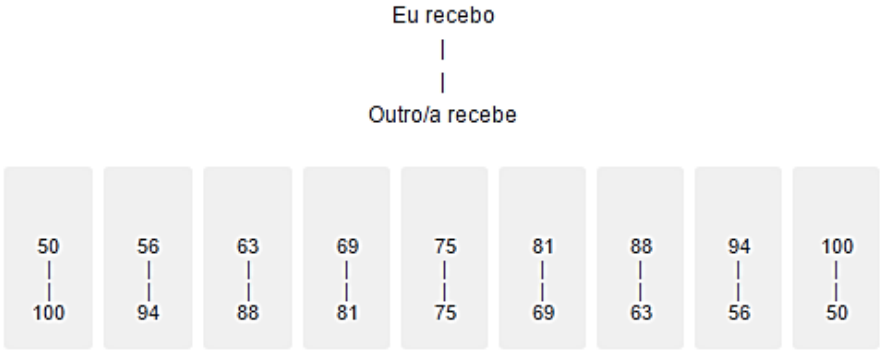


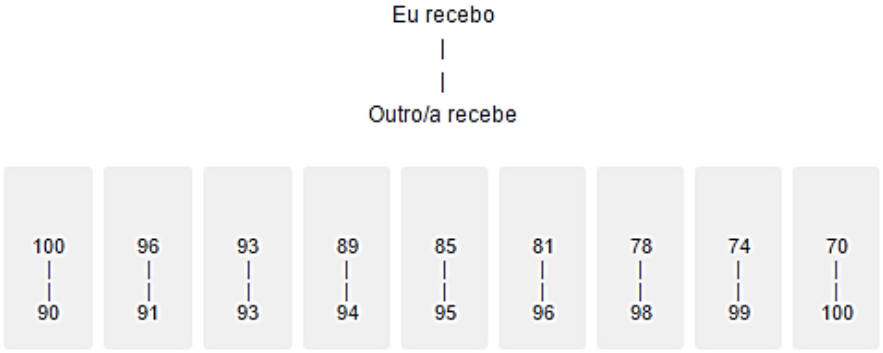


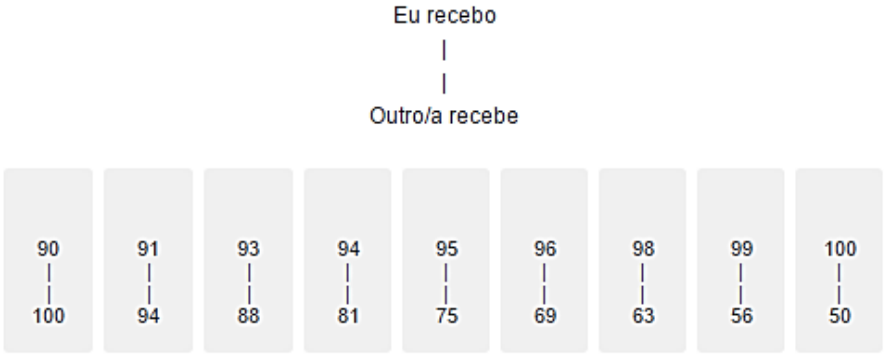

Eu recebo
Outro/a recebe
100 70
99 74
98 78
96 81
95 85
94 89
93 93
91 96
90 100


Eu recebo
Outro/a recebe
70 100
74 96
78 93
81 89
85 85
89 81
93 78
96 74
100 70


Eu recebo
Outro/a recebe
50 100
56 99
63 98
69 96
75 95
81 94
88 93
94 91
100 90


Eu recebo
Outro/a recebe
50 100
56 94
63 88
69 81
75 75
81 69
88 63
94 56
100 50


Eu recebo
Outro/a recebe
100 90
96 91
93 93
89 94
85 95
81 96
78 98
74 99
70 100


Eu recebo
Outro/a recebe
90 100
91 94
93 88
94 81
95 75
96 69
98 63
99 56
100 50

Appendix F: Task display (at beginning of Stage 1)

Appendix G: Written consent

Para verdadeiramente analisar as variáveis de interesse deste estudo houve dois aspectos que não lhe pudemos revelar inicialmente. No jogo online FISH, não chegou a jogar com outros participantes que estavam online mas sim com jogadores pré-programados. Além disso, informámo-lo que iria beber uma bebida açucarada, cujos efeitos eram o interesse do estudo. Contudo, apenas metade dos participantes receberam uma bebida açucarada (~35g açúcar), sendo que a outra metade bebeu uma bebida placebo (bebida com adoçante, 0g açúcar).

Assim, o objectivo deste estudo consistirá em analisar os efeitos de diferentes níveis de glucose no sangue, no desempenho da tarefa FISH.

Para indicar que autoriza a utilização dos dados recolhidos para o objectivo deste estudo, faça uma rúbrica abaixo:

_____

(rúbrica do participante)

Appendix H: SVO calculation (Murphy et al., 2011)

$$\text{SVO}^\circ = \arctan\left(\frac{(\bar{A}_o - 50)}{(\bar{A}_s - 50)}\right)$$

$\bar{A}_O$ = mean allocations for other

$\bar{A}_S$ = mean allocations for self

VIII. Supplementary materials

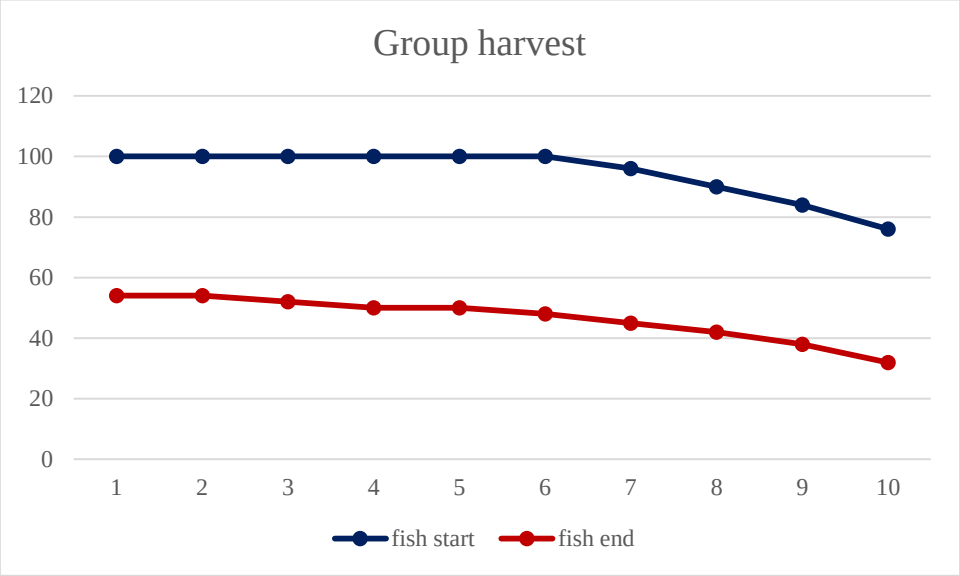
The parameters of each Stage – greed, trend, greed spread and regeneration rate – were selected after conducting several simulations. In these simulations, we focused on the general decay of the pool.

In each simulation, the experimenter participated as one player, since it was not possible to conduct simulations without an "active player". The behavior of the experimenter is described for each simulation. Below we present the results for the simulations of each Stage, where the y axis represents the number of fishes in the pool and the x axis represents the round. In blue we observe the number of fishes at the beginning of each round and in red the number of fishes at the end of the round.

For Stage 1, the parameters were set so that the resource slowly decayed, but with low danger of depleting. In Stage 2, the goal was to deplete the pool very soon. To achieve this, the bots' greed set very high and the regeneration rate of the pool was lowered. Stage 3 had two variations: low threat (same as Stage 1); and high threat. We do not present results for the "Low threat condition of Stage 3, since the parameters are exactly the same as the ones set for Stage 1.In the high threat condition, we chose the parameters that resulted in a progressive decay of the resource – less abrupt than Stage 2, but closer to depletion relatively to Stage 1.

Results of Simulation of Stage 1

The experimenter played by mimicking the harvesting behavior of the bot with 0.5 of greed.



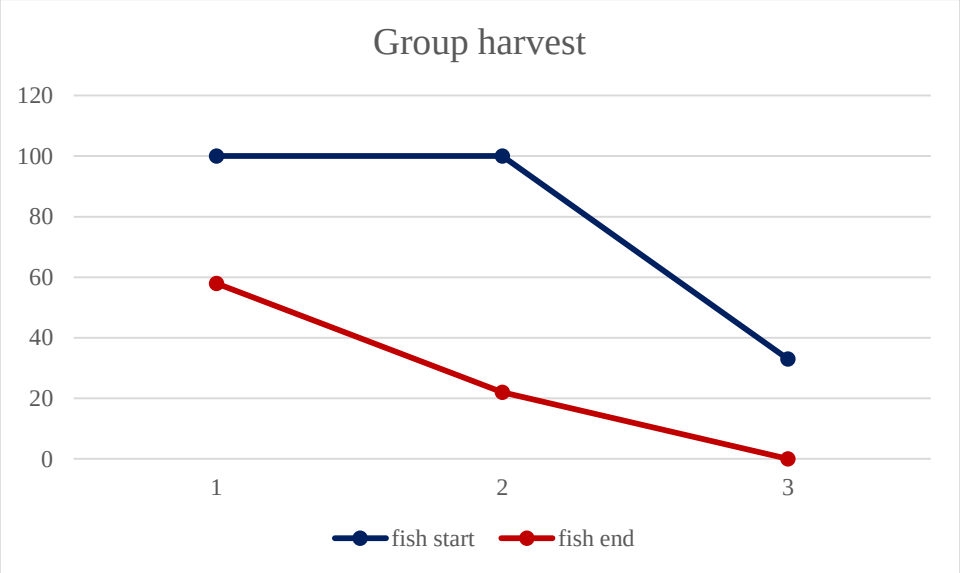
Bot parameters (average greed of 0.5)

- pa2873: greed = 0.3, greed spread = 0.4;
- jo827: greed = 0.8, greed spread = 0;
- td3149: greed = 0.4, greed spread = 0.3;
- cm792: greed = 0.5, greed spread = 0.

Resource parameters: regeneration rate of the pool = 2 x final pool size

Results of Simulation of Stage 2

The experimenter harvested nothing from the resource to make sure the resource would deplete even if participants were cooperative to the maximum.



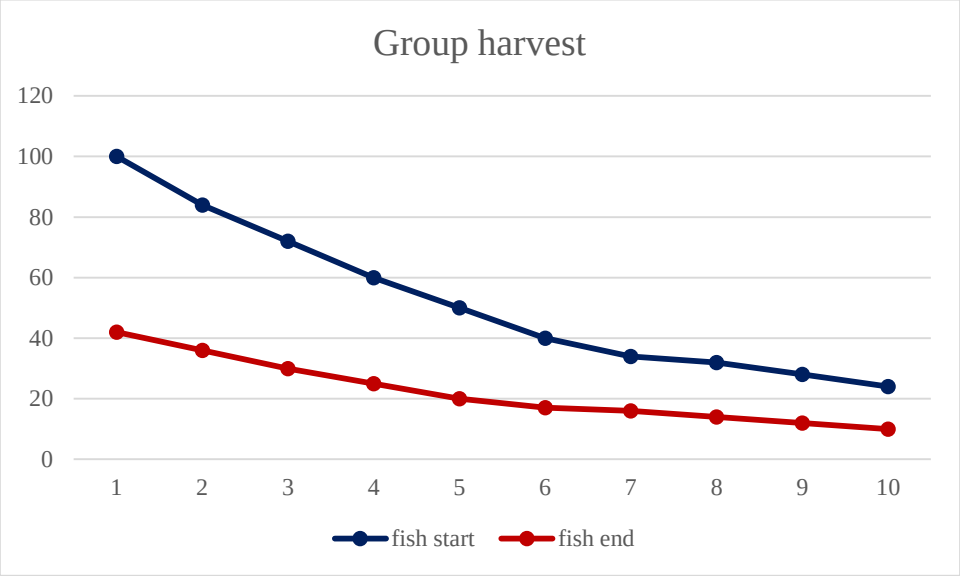
Bot parameters (average greed of 0.5)

- pa2873: greed = 0.7, greed spread = 1.2;
- jo827: greed = 0.9, greed spread = 1.2;
- td3149: greed = 0.75, greed spread = 1.2;
- cm792: greed = 0.85, greed spread = 1.2.

Resource parameters: regeneration rate of the pool = 1.5 x final pool size

Results of Simulation of Stage 3 (High Danger)

The experimenter played by mimicking the harvesting behavior of the bot with 0.5 of greed.



Bot parameters (average greed of 0.6)

- pa2873: greed = 0.75, greed spread = 0;
- jo827: greed = 0.8, greed spread = 0;
- td3149: greed = 0.35, greed spread = 0;
- cm792: greed = 0.5, greed spread = 0.

Resource parameters: regeneration rate of the pool = 2 x final pool size

Measures of cooperation and efficiency

The following measures were retrieved from (Gifford & Aranda, n.d.)

Individual Restraint

1 – taking 0 fish

0.5 – sustainable harvest pattern (with a regeneration rate of 2)

0 – taking 1/N of the pool (too much)

IR < 0 – little restraint

(1- N) – taking all of the fishes for himself

Group Restraint

1 – full restraint, no harvester in the group took any fish

0 – no restraint, harvesters as a group extinguished the resource taking 1/N of the fish each

Individual Efficiency

IE > 1 – taking less than the most efficient amount (preservationist strategy)

1 – perfect efficiency

0 < IE < 1 – stock unable to regenerate to original size after spawning

0 – taking 1/N of the pool (too much)

IE < 0 – even greater inefficiency or greed

Group Efficiency

GE > 1 - underharvesting

1 – perfect efficiency, group as a whole harvests exactly enough to allow full resource regeneration (no more and no less)

$0 < GE < 1$ – greed-based inefficiency

0 – group exhausted the resource

Note: IE for an individual fisher is computed differently when the resource is in danger or not of depletion. The resource is said to be in danger if it can not regenerate to its original size even if all harvesters take nothing (ranges from 1 to negative numbers). GE is also computed differently if the resource is in danger (ranges from 1 to 0)

For additional details on the formulae for each measure of restraint – IR and GR – and efficiency – IE and GE – see Gifford & Hine, (1997)